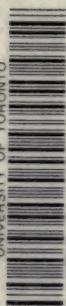
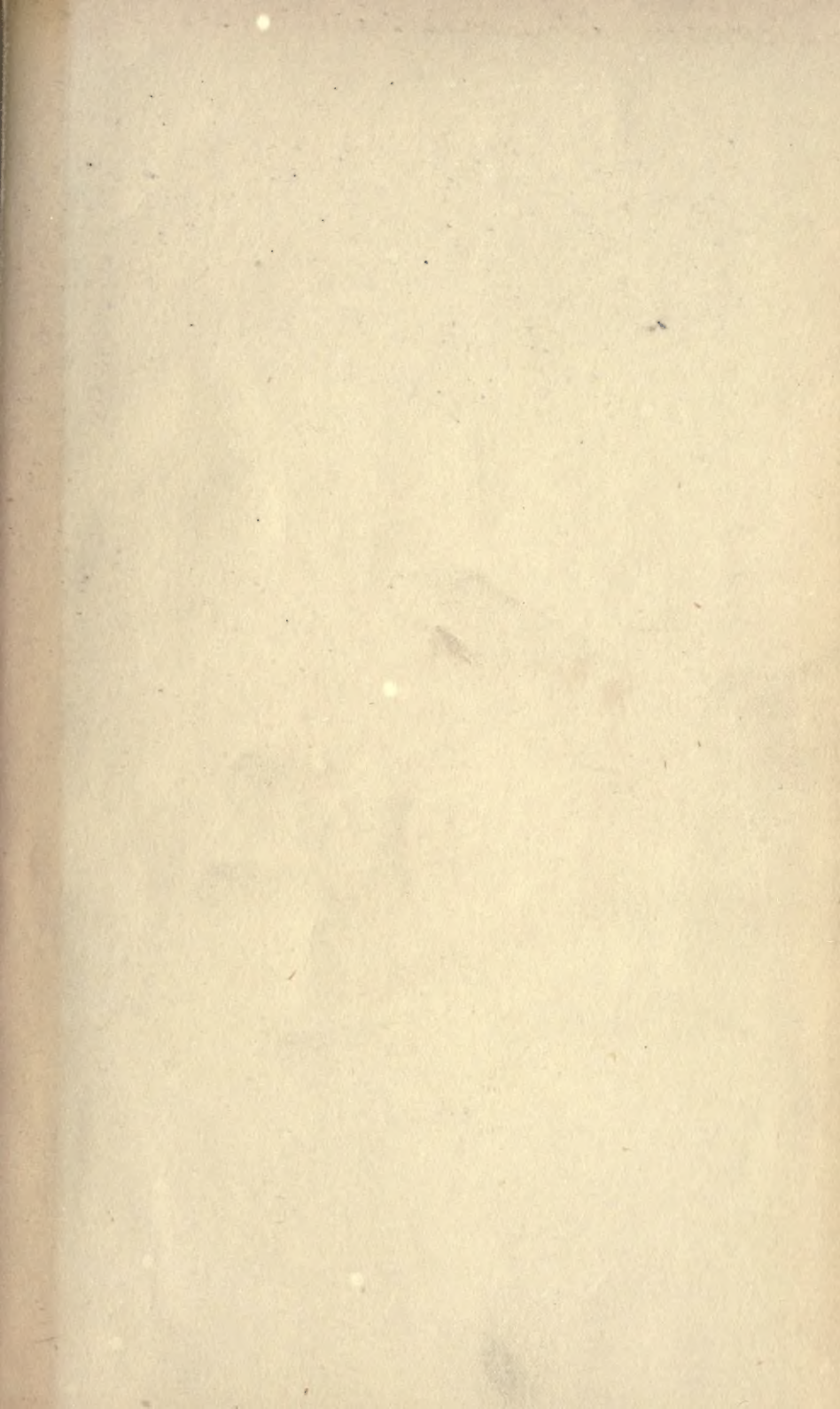



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BY

PROF. LUIGI LUCIANI

TRANSLATED FROM THE ITALIAN

WITH A PREFACE BY

PROF. J. N. LANGLEY, F.R.S.

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HUMAN PHYSIOLOGY

BY

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(295)

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IN FIVE VOLUMES

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CHAPTER I

EXCHANGE OF MATERIAL

SUMMARY.—1. Historical account of researches upon metabolism. 2. Methods employed to determine the qualitative and quantitative data of the balance between intake and output. 3. Two typical examples of balance of exchange of material in man. 4. Difference in the resistance of man and animals to deprivation of food. 5. Inanition and hibernation: relative and absolute loss of weight of the different tissues during abstinence from food; course of the curve of total loss during the three phases of starvation. 6. Consumption of material during fasting deduced from analyses of the urine and respiratory products; influence of size of body, age, sex, and constitution. 7. Exchange upon a diet of meat. 8. Exchange on a diet of fats and carbohydrates with or without the addition of protein. 9. Nutritive value of the digestive products of foods and gelatine. 10. Alcoholic drinks, condiments, spices, and aromatic substances. 11. Water and the mineral salts contained in the ashes of food-stuffs. 12. General conclusions and theory of exchange of material. Bibliography.

FROM our study of the physiology of the organs of *vegetative* and *animal* life we see clearly that life without incessant consumption and transformation of material and energy is inconceivable. With the disintegration of extremely complex and unstable molecules into simpler and more stable ones (exchange of material or *metabolism*), there is, as a fundamental condition of life, a transformation of potential into actual energy (exchange of energy).

Since the chemical metamorphoses of the animal organism result in products which are richer in oxygen than the original substances, it is obvious that these chemical changes consist mainly of oxidation or slow combustion, either direct or indirect processes due to special enzymes (oxidases) which are present and are being formed continually in the living elements of the tissues.

The simplest products of the oxidising processes occurring in the animal organism are water, carbon dioxide, sulphuric acid, and phosphoric acid, in which the elements are combined fully with oxygen. There are, however, many other end-products, which from the chemical point of view represent products of incomplete oxidation; these are represented by more complex

compounds, such, for example, as the combinations of derivatives of ammonia, in which the hydrogen of ammonia is combined with other atomic groups. All these products of consumption are of no further value for the life of the cells and tissues, and are indeed harmful to them; they must therefore be eliminated in order that they may not disturb the normal functions. The total losses thus sustained daily by the organism must be repaired by fresh materials if life is to be maintained; these materials are represented by the food-stuffs and the oxygen, introduced respectively by digestion and respiration.

Hence a continual intake and output of material take place in the organism, the intake being represented by the ingesta, the output by the egesta or the *excreta*. *Metabolism* or exchange of material comprises all the processes which bring about the continuous change and renewal of material in the organism and the study of the different conditions which modify them within normal limits.

Each cell, tissue, or organ has a metabolism of its own. Since they are all nourished and kept alive by the same nutritive fluids, the blood and the lymph, it follows that the difference in their products of assimilation and dissimilation is due to the difference in their chemical, physical, and morphological structure.

The exact determination of the metabolism of the separate tissues and organs is extremely difficult, because in the living organism the amount of their exchange is more or less influenced by all the others, at all events indirectly. The chemical processes, which may be observed in excised organs which are kept alive by means of an artificial circulation, enable us to study and determine the specific qualities of their metabolism up to a certain point, but do not give a physiological measurement. We can, on the other hand, form a sufficiently close estimate of the metabolism of the organism as a whole under different conditions by comparing the quantity and quality of the intake with the output, represented essentially by the urine, the faeces, and the products discharged from the lungs and skin.

In general metabolism the systems of both vegetative and animal life take part. We shall see, indeed, that the nervous system represents the supreme regulator of the exchange of both material and energy. We are justified therefore in dealing with this subject after discussing the two great systems in the life of the higher animals and man.

I. To Sanctorius (born 1561, died 1636) belongs the credit of being the first to make experimental studies on general metabolism. As a lecturer at Padua he published in 1614 a book entitled, *De medicina statica aphorismi*, which contained the results of many years of research upon the increase and decrease of the

weight of his own body, and the influence of various external conditions on those variations.

He compared the weight of the food and drink taken daily with that of the faeces and urine discharged. From these two determinations and the variations in the weight of his body he deduced the quantity of materials lost by *insensible transpiration* through the skin and the lungs.

It had long been known that the weight of an adult may remain almost the same for months and years as the result of an almost perfect balance between the intake and output of material. It was also known that independently of the emptying of the bladder and the bowels the body undergoes a slow and continuous diminution in weight by transpiration. Sanctorius was, however, the first who by long and patient labour measured the variable quantity of this transpiration, and sought to demonstrate the causes determining it. The balance between the intake and output of material may be established not only for the sum total, but also for the separate elements and chemical compounds concerned. These studies only became possible after the discovery of the respiratory gaseous exchange, and after chemistry was sufficiently advanced to allow of the quantitative analysis of the elements and compounds contained in the food taken and in the urine and faeces discharged.

The first important researches into total metabolism were carried out by Boussingault, Sacc, Valentin, Barral, Dalton, and Liebig between 1840 and 1850. Of the utmost importance is the study of the metabolism of nitrogenous substances and the balance of nitrogen, begun in a masterly way by Liebig, and continued by Bischoff and Voit. Great also is the importance of the gaseous exchange, and the balance of carbon, promoted by the classic researches of Regnault and Reiset.

Three different conditions of general metabolism may occur:

(a) There may be almost perfect equality between the intake and output of material, so that the balance of the animal economy as a whole remains the same for a certain period, or is subject to negative or positive variations of a slight and negligible order. In normal adults of middle age this state of equilibrium may last for weeks, months, and even for years; the weight of the body ascertained daily at a fixed hour after the evacuations and before a meal remains almost unchanged.

(b) There may be an increase in the balance of the intake and output of material, that is, there may be a gradual and variable increase from day to day in the weight of the body. This occurs during the whole of the normal anaplastic period or period of growth, muscular development or the deposition of fat in the adult, change from a meagre to a lavish or excessive diet in normal individuals, and during convalescence after febrile disease.

(c) There may be a deficit in the balance when the output of material exceeds the intake, so that the weight of the body diminishes more or less slowly from day to day. This occurs during the cataplastic or involutionary period of old age, total or partial inanition, periods of insufficient nutrition, and during acute or chronic wasting diseases.

The methodical testing of the total weight of the body at regular intervals will therefore suffice to give a rough idea of the total exchange of material, to tell us whether the total output is much the same as the intake, or whether there is a considerable surplus or gradual deficit in the balance. The comparison of the separate elements of the material taken in and discharged is, however, of much greater interest. It enables us up to a certain point to ascertain what substances are formed or consumed in the organism. Thus, for instance, from a separate balance of the intake and output of nitrogen and carbon we can reckon approximately, as we shall see later, the quantity of protein and fat formed and consumed from day to day in subjects under definite conditions of environment and diet.

We must, however, point out that the majority of the results obtained in these researches on metabolism by numerous experimenters have a merely approximate value and must be accepted with caution, because the methods employed cannot give absolutely accurate numerical data; and small mistakes in data, grown more serious during calculation, may lead to altogether wrong conclusions. The recent perfecting of methods of research and the estimation of their inherent inaccuracies have, however, effected a great advance in this vast field of physiological investigation. These researches enable us to determine the conditions favourable to the disintegration or reintegration of the tissues, especially the development or atrophy of the muscles which form but little less than half the mass of the body, and the deposition or consumption of fat; to estimate the nutritive value and, generally, the different uses of the various groups of food-stuffs; to establish the basis for the theory of nutrition, *i.e.* to determine the average alimentary regimen of man; and, finally, to ascertain the internal regulating forces and, as far as possible, the laws of chemical changes in the animal economy.

II. The animal's daily intake of material is represented by the food taken and the oxygen absorbed by pulmonary and cutaneous respiration; the output, on the other hand, by the products of consumption discharged by the kidneys, intestines, lungs, and skin. An exact determination of the intake would require a complete chemical analysis of the food, in order to ascertain the quality and quantity of protein, fat, and carbohydrate contained in it—an analysis which would demand too much time and labour, and has therefore never been made by any experimenter. In order to

simplify the task, the plan has been adopted of putting the subject of the experiment on as simple a diet as possible, one composed of the commonest vegetable and animal foods, which are easily and completely digested and have a known and constant composition. The same quantities of these articles of food are given to the subject of the experiment every day. In order to obtain reliable results the experiment must extend over a sufficiently long period, at least a week, so that in the daily average of the intake, the errors inherent in the method may not accumulate but balance one another, at all events partially.

In order to form an approximate estimate of the quantity of protein contained in the articles of food chosen for the experiment, the nitrogen contained therein is generally ascertained by Kjeldahl's method. The amount of nitrogen multiplied by 6.25 gives the quantity of protein contained in the food. Since the nitrogenous substances in animal and vegetable foods are not all found in the form of protein, it is obvious that this method does not give us the exact quantity for all the nitrogenous substances introduced.

In order to ascertain the quantity of fats contained in the food, a sample is extracted with ether, and thus the total quantity of fats can be calculated. This method also is by no means free from error; on the one hand, ether dissolves some non-fatty substances, and on the other, only dissolves free fats, leaving undissolved those which are more or less closely bound up with protein.

The total quantity of carbohydrate is usually estimated indirectly in the following way: a sample of the food is evaporated at a temperature of 100°C ., leaving the dry residue, which serves for the calculation of the quantity of water contained in the whole amount of food taken; by combustion of the dry residue is obtained the ash, from which the quantity of salts in the food may be ascertained. Subtracting the weight of the ash from that of the residue, and also the weight of albumen and fat which has already been ascertained, one obtains a remainder which represents the weight of carbohydrate. This indirect determination is obviously the least accurate, since in it are accumulated all the errors of analysis inherent in the preceding direct determinations.

In order to estimate accurately the excreta, the urine and faeces evacuated in twenty-four hours must be collected, and determinations made of the weight, dry residue, ash, and single elements (N, C, H, O, S, P) resulting from the oxidation of the three groups of organic substances in the food. It is known that nitrogen, sulphur, and phosphorus are derived from protein, whereas carbon, hydrogen, and oxygen arise from protein as well as from fat and carbohydrate.

These researches may be very much simplified when, for the

estimation of the total consumption of protein, we confine ourselves to determining the total amount of nitrogen in the excreta by Kjeldahl's method, and pay no attention to the sulphur and phosphorus. If we multiply the nitrogen by 6.25, we can calculate, as we have already seen, the sum total of protein consumed.

In order to estimate the total consumption of non-nitrogenous substances, fats and carbohydrates, we may confine ourselves to determining the total amount of carbon in the excreta. Since the proportion of nitrogen to carbon in protein is as 16 to 52.8, we can easily calculate the carbon in the protein consumed, and obtain by subtraction the carbon resulting from the decomposition of the non-nitrogenous organic substances.

In order to complete the list of materials taken in and discharged, and obtain a balance of account, we must not only analyse the food, urine, and faeces, but also determine, at least approximately, the total quantity of oxygen absorbed, and carbon dioxide and water discharged, by the lungs and skin.

For the estimation of the quantity of oxygen, carbon dioxide, and water-vapour absorbed or eliminated by the lungs and skin, the animal or man is shut up in an airtight chamber, and the changes which the breathing of the subject produces in the air during its passage through the enclosed space are determined.

Various kinds of apparatus have been suggested by physiologists for the study of gaseous exchange in animals and man. We will describe the most important of these, referring more particularly to those which can be used for man. They may be arranged in three groups, according to the different principles on which they are based.

(a) The quantities of oxygen absorbed and carbon dioxide discharged by the lungs and the skin are determined at the same time.

(b) The carbon dioxide only is determined directly.

(c) The respiratory gases from the lungs only are determined.

Each of these methods possesses, as we shall see, its own advantages, and may be used in preference to the others in certain cases.

(a) The classical apparatus of the first group is that used originally for small mammals by Regnault and Reiset. As will be seen from the diagram, Fig. 1, it consists of a glass bell-jar *A*, in which the animal to be experimented upon is placed, surrounded by a larger cylinder, also of glass, kept full of water in order to limit the variations of temperature. Through the upper aperture of the bell-jar, which is hermetically closed with a stopper, pass four glass tubes, two of which are connected with the apparatus for the absorption of the carbon dioxide produced by the animal. One of these tubes ends above, the other is continued almost to the bottom of the bell-jar; they communicate with two receptacles *C* and *C'*, which are half-filled with a titrated solution of caustic soda. By means of the contrivance *K* these two receptacles are alternately lowered and raised, so that, while the one which is lowered withdraws air from the bell-jar, the other, which is raised at the same time, restores exactly the same amount. The air, when it comes into contact with the soda, loses its carbon dioxide, the quantity of which is determined at the end of the experiment by another titration of the solution of soda.

The third tube, which passes through the stopper of the bell-jar, conveys pure oxygen, which is driven from the receptacle *N* (or *N'* or *N''*, which take

the place of *N* as soon as the latter is empty) by the water coming from the cistern in which it is always kept at a constant level. Before entering the bell-jar the oxygen passes through the filtering bottle *M*. The fourth tube in the opening of the bell-jar communicates on the one hand with a mercurial manometer *a b c*, showing the gaseous pressure prevailing in the interior of the system, and on the other hand with a U-shaped tube containing mercury (*r' d*), which serves for the removal of samples of air from the bell-jar.

If we determine the composition of the air in the bell-jar before and after the experiment, the quantities of carbon dioxide discharged and oxygen absorbed during the experiment, it is obvious that we can by this method readily ascertain the gaseous respiratory exchange of a small animal during the period of several hours spent by it in the apparatus.

One of the drawbacks of this method is that the animal is forced to

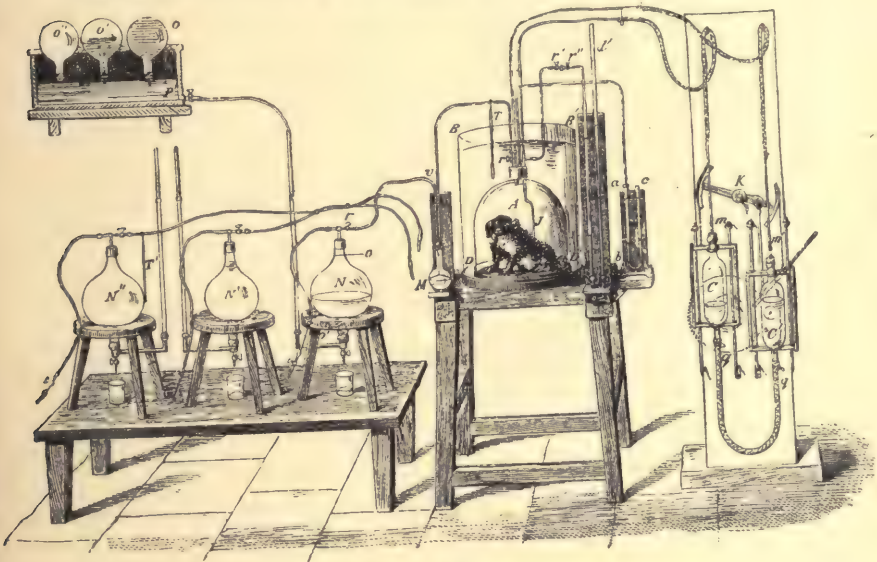


FIG. 1.—Apparatus of Regnault and Reiset.

breathe in a fixed volume of gas, so that during inspiration the gas is rarefied, whilst it is compressed during expiration. This makes the respiratory movements difficult, and is perhaps not without influence on the course of the normal processes of gaseous exchange. Another drawback in the apparatus of Regnault and Reiset is that the absorption of carbon dioxide is both slow and difficult.

Later methods, based on the same principle as the apparatus of Regnault and Reiset, have endeavoured to obviate this defect. Amongst these methods we may mention that of Grandis (1909) for animals and that of Hoppe-Seyler for man; the latter we will now describe.

As will be seen from Fig. 2, the subject of the experiment is shut up in the large chamber *A*, having a capacity of 4.8 cubic metres, and from which, through two wide tubes, air is alternately withdrawn and restored by means of the pump below, which is kept constantly in motion by a water motor. The air is thus brought into contact with a strong solution of caustic potash, contained in two flasks (*B, B*), and is thus deprived of carbon dioxide. Oxygen is forced through a narrow copper tube into the chamber by a

gasometer *C*. Before mixing with the air of the chamber it passes through a filtering bottle containing caustic potash and also through a meter, which registers the quantity of oxygen entering the chamber.

(*b*) Pettenkofer objected to apparatus constructed on the preceding principle, on the ground that in course of time products of the exhalations of the body, which are injurious to health, accumulate and are not fixed by potash, as is the carbon dioxide. He therefore in collaboration with Voit

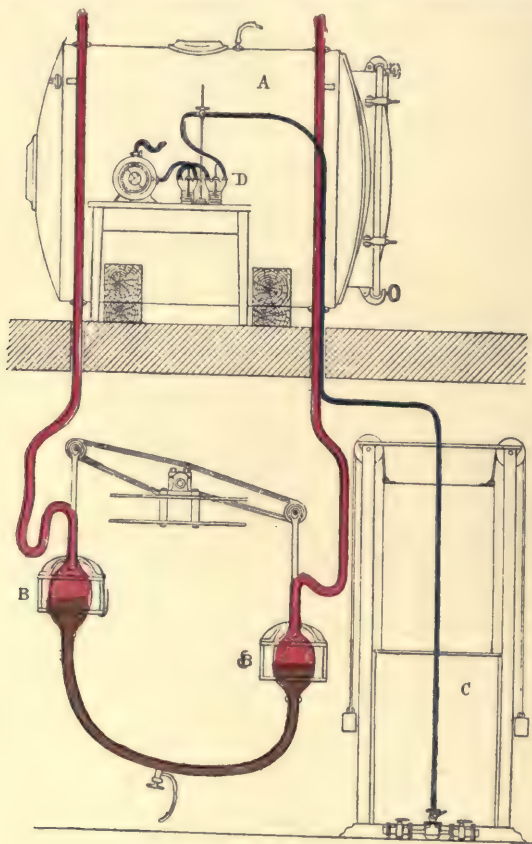


FIG. 2.—Apparatus of Hoppe-Seyler.

invented an apparatus in which there is continual ventilation; no direct determination of oxygen was made, but only of carbon dioxide and aqueous vapour.

Tigerstedt and Sondén greatly increased the space in which the subject of the experiment is confined, by making use of an ordinary room with a capacity of 100·6 cubic metres, and with walls, floor, and ceiling rendered impermeable to air by sheets of zinc. By means of a water-pump the air in the room is continually removed and replaced by fresh air from outside. The volume of air is measured by gas meters, and the quantity of carbon dioxide contained in it is ascertained from time to time by samples taken from the total quantity.

(c) All the various forms of apparatus hitherto described are generally used for experiments lasting several hours or even whole days. If, on the other hand, we desire to study gaseous exchange for a brief period, and more especially if we wish to ascertain the influence of certain conditions of short duration, such as muscular work, we make use of those methods in which the respiratory tract is placed in direct connection with the apparatus. It is obvious that in these methods only the gaseous exchange of the lungs is taken into account, but this is to a certain extent justified by the fact that gaseous exchange is effected mainly through the lungs. According to Zuntz only 1 per cent of the carbon dioxide eliminated and the oxygen absorbed in normal conditions passes through the skin. (See Vol. I. Chap. XXIII.)

The principle on which the various methods devised for this purpose are based is that of breathing through the mouth, the nasal passages having

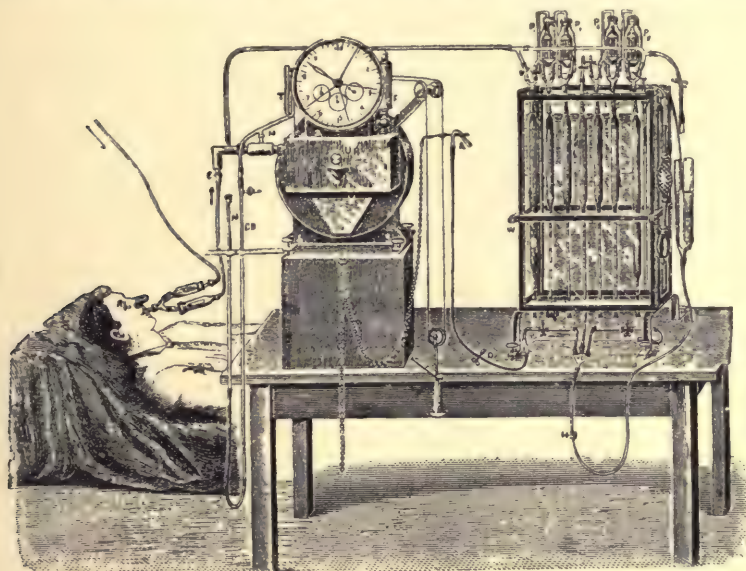


Fig. 3.—Apparatus of Zuntz.

been closed by a clip, by means of a tube fitted with two valves of the kind invented by Müller, which separate the air inhaled from that exhaled. The valves used by Lovén and Speck are of this type.

Speck, who with Smith was the first to make experiments of this kind, used two separate gasometers, from one of which he drew the air inspired, and in the other collected the air expired.

Geppert and Zuntz simplified and improved the method, by replacing the cumbrous gasometers by a gas meter and confining themselves to samples of the expired air, the composition of the atmospheric air inhaled being already known and constant.

The apparatus of Geppert and Zuntz consists of three parts, as shown in Fig. 3: a valvular apparatus which separates the air inspired from that expired, allowing only the latter to pass into the meter; a gas meter, and an apparatus for the analysis of samples taken from the total quantity of the air expired and the volumetric determination of the quantities of both carbon dioxide and oxygen. This apparatus is used for laboratory researches and

when the person experimented on is in a state of rest. Zuntz has, however, lately introduced modifications of the method, which permit its use in experiments on persons who are moving about. As is shown by Fig. 4, the



FIG. 4.—Portable Apparatus of Zuntz.

apparatus then becomes portable as a knapsack. The most important of the alterations made by Zuntz in this apparatus consists in substituting for the heavy water meter a so-called dry meter, in which the volume of gas is measured by flexible leather bellows.

The quantitative determination of the water and carbon dioxide contained in the air breathed during a certain time will enable us to estimate accurately the quantity of carbon and hydrogen lost through the lungs and skin. The average results obtained from the study of general metabolism show that about nine-tenths of the carbon introduced in the food are eliminated in the form of carbon dioxide, and only one-tenth is combined in the organic pro-

ducts of the urine. It was also found that about four-fifths of the total quantity of hydrogen in the food are in the form of water, and only one-fifth leaves the body in the urinary products.

It is doubtful whether all the nitrogen introduced in the food is found in the nitrogenous products of the urine, sweat, and faeces, or whether a not inconsiderable portion is discharged in a gaseous form with the air expired. The results obtained by Regnault and Reiset, Seegen and Nowak prove that the air expired contains a slight excess of nitrogen, on an average 0.004 grm. in rabbits, 0.007 in dogs, per kgrm. and hour. This fact may be explained by the inaccuracy of our methods of research. Leo, indeed, proved that this excess diminishes in proportion to the care taken to avoid such errors. He reduced the excess in the nitrogen expired by rabbits to less than one-tenth of that found by Seegen and Nowak.

A certain small quantity of nitrogen might be discharged in a gaseous form with the air expired, owing to the decomposition of the nitrogenous substances introduced in the food. The experiments made by Krogh on fertilised eggs and mice and by

Oppenheimer! on rabbits and dogs negative this supposition. In any case it may be considered without appreciable inaccuracy that in researches upon metabolism the total quantity of nitrogen contained in the urine, sweat, and faeces represents the whole amount of nitrogen derived from the protein consumed.

The nitrogen discharged in the urine in twenty-four hours by an adult man amounts on an average to 15-16 grms., but is subject to considerable variations according to the quantity of nitrogenous food and the different conditions peculiar to the person in question.

During the secretion of sweat there is discharged from the skin in addition to water a certain quantity of solid nitrogenous substances, especially in the form of urea. In the profuse sweating caused by a Turkish bath, and also by heavy muscular work, the quantity of nitrogen lost by the skin may, according to Argutinsky's researches, amount to as much as 0.25-0.26 gm. According to Atwater and Benedict the quantity lost through the skin by a man at rest and exposed to the ordinary temperature of a room is 0.025 gm. per day, whereas the corresponding figure for a man at work is 0.29. In researches on metabolism it is, however, usual without incurring any serious error to leave out of account the nitrogen lost through the skin. In the same way we may leave out of our reckoning the quantity of nitrogen lost with the desquamation of the horny substance of the epidermis, and the falling out of hair, a loss which was exaggerated by Moleschott owing to faulty methods.

The nitrogenous substances contained in the faeces may arise in two ways: some represent the remains of incompletely digested food which have not been absorbed, and others are excretory products eliminated with various digestive juices, and mixed with degenerate epithelial cells and intestinal bacteria. The non-utilised remains of food disappear from the faeces during fasting and when the food is devoid, or almost devoid, of protein. According to the researches of Rubner, Rieder, Tigerstedt, and Renvall the faeces formed daily in the intestines of a fasting man contain on an average 0.11-0.35 gm. of nitrogen; when the diet is either poor in nitrogenous substances or totally devoid of them, they contain 0.5-1.5 grms. of nitrogen. We may therefore conclude that the quantity of nitrogen discharged with the faeces as a metabolic product is by no means negligible. It may be estimated as an average of 1 gm. per day, inclusive of that contained in the bacteria. It is, however, certain that with an ordinary mixed diet, a considerable portion of the nitrogen discharged with the faeces represents the residue of the food. It is therefore on theoretical grounds equally wrong to add this nitrogen to that found in the urine, thus reckoning it with the output, or to subtract it from that contained in the food when considering the intake. In both cases, however, the inaccuracy is a negligible

one, when the magnitude of the figures for the balance of the intake and output is taken into consideration.

As regards the non-nitrogenous substances contained in the faeces, it is well to remember that a noteworthy amount of fat can always be extracted from them with ether, even when the food is devoid of fat and even from the faeces formed during fasting. Rubner found that the faeces contained 3.1-6.5 grms. of ethereal extract when the diet of an adult consisted solely of bread or macaroni, which contain a very small quantity of fat. It may therefore be assumed that when the quantity of fat contained in the faeces in twenty-four hours does not exceed 6-7 grms., it does not represent a residue of fatty foods, but an excretory product which is to be reckoned with the output. Likewise in Atwater's researches with an ordinary mixed diet the quantity of fat in the faeces varied from 2.1 to 13.4 grms., an average of 5.1 grms. per day.

There is also found in the faeces a certain quantity of carbohydrate, varying with the nature of the food. We know, in fact, that cellulose is not attacked by the digestive juices, but only by a process of fermentation set up by bacteria, and requiring the retention of the food for a long time in the intestines, which is not the case in man. It is therefore obvious that the quantity of carbohydrate in the faeces will be the smaller the less the cellulose introduced with the food. This is confirmed by the observations of Rubner, Hultgren, and Landergren. On a diet of brown rye bread the daily quantity of carbohydrate in the faeces varies from 38 to 72 grms.; on a diet of white bread, macaroni, and rice it does not exceed 13-14 grms.

Without any considerable error it is possible to estimate indirectly the quantity of carbon contained in the faeces by taking as a basis the proportion between the nitrogen and the carbon, which according to Atwater and Benedict's investigations has a mean value of 1:9.2.

III. A clear and instructive example of the total balance of the intake and output of the human body is given by Schenck and Gürber (1900). The subject of the investigation was an adult man, living on meat, bread, butter, potatoes, common salt, and water. His initial weight was 70 kgrms. He remained at rest for twenty-four hours in the chamber of Voit's respiratory apparatus, and at the end of the experiment he had gained 139 grms. in weight.

The nutritive substances taken were as follows:

		Grms. of Carbon.	Grms. of Nitrogen
Protein	130 grms. containing	69	21
Fat	100 " "	76	...
Carbohydrate . . .	400 " "	176	...
Salts.	30 " "	...	...
Water	2100 " "	...	...
<hr/>		<hr/>	<hr/>
Total intake of food	2760 " "	321	21

The output in the urine, faeces, and breath was :

		Water.	Salts.	Carbon.	Nitrogen.
Urine	1355 grms., of which	1280	24	14	19
Faeces	120 " "	85	6	16	2
Products of respiration .	1867 " "	950	...	250	...
Total output	3342 " "	2315	30	280	21

A comparison of the totals for intake and output with the weights of the subject before and after the experiment will indicate the oxygen absorbed. As already mentioned, the subject gained 138 grms. in weight.

From the above data we can make an approximate calculation of the total amount of oxygen absorbed according to the following equation :

$$\begin{aligned}
 \text{Oxygen} &= (\text{final weight of the body} + \text{output}) - (\text{initial weight} + \text{intake}) \\
 &= (70138 + 3342) \text{ grms.} \quad \quad \quad - (70000 + 2760) \text{ grms.} \\
 &= 720 \text{ grms.}
 \end{aligned}$$

We now have all the requisite data for a table showing the balance of the exchange of material.

Balance of Total Exchange.		Carbon.	Nitrogen.	Salts.			
<i>Intake :</i>							
Food	2760 grms.	321 grms.	21 grms.	30 grms.			
Oxygen	720 "						
	— 3480 grms. } containing						
<i>Output :</i>							
Urine	1355 grms.	280 "	21 "	30 "			
Faeces	120 "						
Products of re-	1867 "						
spiration							
	— 3342 grms. } containing						
Difference + 138 grms., containing		+ 41 grms.	0 grms.	0 grms.			

The results of these investigations showed that the subject had gained 138 grms., containing 41 grms. of carbon. Since there was perfect equilibrium on the balance of nitrogen, the increase in weight cannot be due to an accumulation of protein ; we are therefore justified in concluding that there is a deposition of non-nitrogenous material.

From the above data we can estimate fairly accurately whether the 41 grms. of carbon were retained in the form of fat or carbohydrate, by noting the size of the respiratory quotient, *i.e.* the ratio between the carbon dioxide discharged and the oxygen absorbed. If we subtract the 950 grms. of water exhaled from the sum total of the respiratory products, which amounted to

1867 grms., we have the approximate amount of carbon dioxide discharged = 917 grms., whereas the oxygen absorbed was = 720 grms.

If the volumes of carbon dioxide discharged and oxygen absorbed are calculated from these weights, the respiratory quotient is as follows :

$$RQ = \frac{\text{vol. CO}_2}{\text{vol. O}_2} = \frac{464}{503} = 0.92.$$

This quotient of 0.92 is very nearly 1, which implies that carbohydrates were chiefly consumed, these substances giving by combustion a volume of carbon dioxide equal to the volume of oxygen absorbed, that is, a quotient of 1. This quotient is much higher than that given by the complete combustion of fats, which is 0.71, from which it follows that little of the fat introduced as food was burnt, and consequently all the carbon retained in the organism was in the form of fat.

If all the 41 grms. of carbon retained are represented by fat, the subject of the experiment had stored up 55 grms. of fat. Since his weight increased by 138 grms., there is an excess of 85 grms., which can only represent water retained. The balance of water, on the other hand, shows that 2100 grms. of water were taken and 2315 eliminated, *i.e.* 215 grms. more. We must, however, take into account the fact that water is generated in the body during combustion. The oxidation of the carbohydrates, protein, and fat produced respectively 224, 54, and 30 grms. of water, a total of 308 grms. If we take 215 grms. from this total, we find that 93 grms. of water are retained. The figure (93) resulting from this calculation differs but little from that (85) arrived at above. The difference falls within the limits of experimental error and of the rounding of the figures customary when making the calculation.

Another typical example of investigation of exchange of material, carried out with the utmost exactitude and for a period of four days, is shown in the following table drawn up by Atwater and Benedict. The subject was a man 34 years of age, and about 64 kgrms. in weight, and he kept as quiet as possible in a state of repose for the four days. The table shows the daily average of the intake and output with the exception of the oxygen consumed :

[TABLE

INTAKE IN GRMS.

Food.	Water.	Protein.	Fat.	Carbo- hydrate.	Nitrogen.	Carbon.	Hydrogen of organic Food-stuffs.
Meat . . . 160	105·6	44·5	6·7	...	7·1	28·4	4·2
Butter . . . 70	7·4	0·8	59·9	...	0·1	43·8	7·1
Skim milk . . 450	405·9	17·1	0·5	22·5	2·8	19·6	2·8
Bread . . . 310	129·3	24·5	8·7	143·5	3·9	84·7	12·7
Maize biscuit . 50	2·9	5·5	4·2	36·5	0·9	22·4	3·2
Sugar . . . 64	...	...	...	64·0	...	26·9	4·2
Gingerbread . 30	1·4	2·0	2·5	23·3	0·3	13·2	2·0
Water . . . 1500	1500·0	...	...	...	...	...	...
Total . . . 2634	2152·5	94·4	82·5	289·8	15·1	239·0	36·2

OUTPUT IN GRMS.

Urine . . . 1449·5	1403·1	...	...	...	16·2	12·2	3·5
Faeces . . . 54·7	40·6	5·4	3·7	3·2	0·9	7·4	1·0
Products of respiration . .	962·8	...	...	...	...	207·3	...
Total	2406·5	...	...	...	17·1	226·9	4·5
Balance . . .	-254·0	...	...	...	-2·0	+12·1	+31·7

As we have already shown, it is a matter of indifference in a calculation of the exchange whether we consider the organic substances discharged in the faeces as products of consumption or as non-absorbed remains of food. In the former case, they are included in the output, as is shown in the table; in the latter case, they must be deducted from the intake. If, following Tigerstedt, we adopt the latter expedient, it would follow that the subject of the experiment had a daily allowance of 89 grms. of protein containing 14·2 grms. of nitrogen, 78·8 grms. of fat, and 286·6 grms. of carbohydrate. Since 16·2 grms. of nitrogen were discharged in the urine, there is a deficit of 2 grms. in the balance of nitrogen; in other words, the subject lost 12·3 grms. of protein from his own tissues. The total consumption of protein was 101·5 grms., while 89 grms. were absorbed; so that the diet contained 12·5 grms. too little to cover the consumption and maintain nitrogenous equilibrium.

The table, moreover, shows a gain of 12 grms. in carbon; in other words, the organism accumulated a certain quantity of non-nitrogenous organic substances, containing altogether 12 grms. of carbon. We now have to ascertain whether fats or carbohydrates have been deposited.

The total quantity of carbon eliminated comes either from the protein, fat, or carbohydrates. The average proportion between the nitrogen and the carbon in the protein being, according to the researches, made by Rubner, as 1:3.28, it follows that in the combustion of all the protein 3.28×16.2 , that is, 53.1 grms. of carbon, were involved. The total quantity of carbon found in the gaseous products of the pulmonary and cutaneous respiration and in the urine amounted to 219.6 grms. of carbon; we have therefore 166.5 grms. of carbon to distribute among the non-nitrogenous food substances, that is, the fats and carbohydrates.

If we knew the total amount of oxygen consumed during the experiment it would be easy to deduce from the value of the respiratory quotient whether the material deposited consisted of fat or carbohydrate. The problem can, however, be solved fairly accurately by simply taking into account the composition of the diet and the faeces which pertain to it. Many researches have indeed proved that during metabolism carbohydrates are burnt more quickly and readily than fats. We may then legitimately assume that the remaining 166.5 grms. of carbon are derived from the carbohydrates absorbed, and that any excess over their content of carbon may be reckoned as fat consumed.

The carbohydrates absorbed amounted, as already stated, to 186.6 grms. which contain 124.7 grms. of carbon. There is then a remainder of 41.8 grms. of carbon derived from the combustion of fat, that is to say, that in addition to all the carbohydrates, 54.6 grms. of fat have been burnt.

We therefore conclude that the subject of the experiment consumed daily an average of 101.5 grms. of protein, 286.6 grms. of carbohydrate, and 34.6 grms. of fat. If we compare the intake and output, we find that the individual in question lost about 12 grms. of protein and gained about 24 grms. of fat.

A perfect equilibrium between the intake and output of material, so that the weight of the body remains unchanged, does not obtain. Even under the most regular and uniform physiological conditions in adults the equilibrium is unstable; the weight varies slightly from day to day, from week to week. There is a dynamic equilibrium; certain chemical components of the organism are consumed and are replaced by others derived from the food. That the components thus substituted are not identical either as regards quality or quantity with those which are decomposed is proved by the fact that the composition of the body—even when its weight is only subject to slight positive or negative variations—changes slowly and constantly with age.

IV. The total amount of the exchange of material varies considerably with varying conditions, but is mainly dependent on the quantity and quality of the food taken. When, therefore, the subject is deprived of food, we have the simplest case of

metabolism, one which should logically be studied before the exchange which takes place on the introduction of various kinds of food-stuffs.

During a fast the animal organism takes in oxygen only, and this serves for the combustion of the organic substances which form the reserves stored up from past meals, or constitute the living foundation. During fasting, therefore, there is no cessation of consumption although no material for repair is introduced from outside; the result is a continuous loss of weight, which forms the most obvious and invariable sign of the *process of inanition*, during which the organism consumes itself, *i.e.* some elements of its tissues, although to a very different extent in the different tissues.

The *metabolism during inanition* is a starting-point of the utmost importance for the interpretation of the phenomena of the normal exchange under different forms of nutrition, the investigation of the extent of this exchange, and the development of the *theory of nutrition*, the determination of the alimentary needs of the organism under different physiological or abnormal circumstances.

We must first answer certain preliminary questions: How does the power of resistance to inanition differ in various animals? How far is inanition compatible with life, and how does it lead to death? Can the normal state of the most important functions of the organism be preserved during fasting for a certain length of time?

Experiments have shown that the power of resistance to fasting is considerably greater in both men and animals than is commonly supposed. The animal most frequently used in such researches is the dog. Data supplied by various authorities prove that the average duration of inanition in the dog is 33 days (Richet). Adults have more power of resistance than the young, fat subjects more than thin, the time varying from 20 to 60 days. As a rule, carnivorous animals resist longer than herbivorous: the cat 20 days, the rabbit 13 at most. Large mammals resist longer than small ones, even when they are varieties of the same species: the pig 34 days, according to Colin; mice 2 or 3 days, according to Redi, Colin, and others.

The duration of inanition in birds is also considerable. For the hen 14 days on an average, the pigeon 11, the eagle, according to Buffon, 35 days. Cold-blooded animals stand inanition for a marvellously long time: salmon 8-9 months, rattlesnake 27 months, python 23 months, the frog, chameleon, and salamander 12 months; tortoise 18 months, viper 20 months.

Hence there is a great difference in the duration of life in the various classes and species of animals, and no small difference even between individuals belonging to the same species. One

fact is, however, common to all animals, whether higher or lower, warm- or cold-blooded, small or large: they all die of inanition when they have lost about 40 per cent of their weight. This 40 per cent is only an average figure, which is not always reached, as in the case of the mouse, and is often exceeded. Thus in one dog the loss amounted to 44·19 per cent, in another 48·53 per cent; Falk records another of 49 per cent, and Fede one of 50 per cent, half the original weight, which is probably the maximum loss compatible with life.

The process of inanition is of long or short duration according as the loss or consumption takes place slowly or rapidly. For this reason it lasts longer in cold-blooded than in warm-blooded animals, in adults than in the young, in large animals than in small ones, etc. It is to be expected that man should form no exception to this rule, and his power of resistance to fasting should not differ to any marked degree from that of the higher mammals. Very few people, however, believe this *a priori*, because very few have tried a long fast, and the sensations of hunger experienced after a few hours of fasting make them think it impossible to survive a long fast. Both ancient and modern literature, however, afford instances of extremely long fasts endured by man. We may leave out of consideration ascetic and pseudo-scientific literature, which very often deals with legendary cases, although it records not a few well-authenticated facts. If we confine ourselves to the modern literature dealing with authenticated fasts, we may distinguish between fasts resulting from misfortune, voluntary fasts undertaken with suicidal intent, fasts as the result of disease, and experimental fasts.

(a) Fasts resulting from misfortune are of very little value to us because they are accompanied by serious complications which disturb the normal course of inanition. A classical example is Dr. Savigny's description of the wreck of the *Medusa*, which took place in 1816.

(b) Fasts undertaken with a view to suicide are likewise of little value for the determination of the normal course of inanition. The case of the lawyer Viterbi is, however, interesting. He was condemned to death on a charge of assassination, and starved himself to death in order to avoid execution, keeping a diary in which he stoically recorded his sufferings. He died after only 17 days, but he abstained almost entirely from water. The story of the assassin William Granier is less clear as to the strictness of the fast, which lasted over two months, during which he drank from time to time.

(c) Of fasts undertaken during disease, the case of the alchemist Duchanteau, related by Diderot, is remarkable. He fasted for 25 days, during which he drank his own urine. There are numerous cases of prolonged fasts among sitophobes, recorded in lunatic

asylums before the introduction of forcible feeding. Some of these fasts lasted as long as twenty to thirty or even forty days before death from exhaustion supervened.

(d) The fasts of most use to us are those undertaken voluntarily for the purposes of experiment. Ranke, Pettenkofer, and Voit were the first to make experiments to study the metabolism of man during a fast of two or three days. Lehmann, Müller, J. Munk, Senator, and Zuntz (1893) studied fasts of seven to ten days in the professional fasting men, Cetti and Breithaupt; Johansson, Sondén, Landergren, and Tigerstedt (1898) studied a five days' fast in a medical student. A long experimental fast was that undertaken by the professional fasting man, Succi, whom I studied in Florence in 1888 with the help of some junior assistants. This fast lasted thirty days, during which there was a loss of weight of about 19 per cent. This is not the longest well-attested fast. It is well known that Dr. Tanner, an American, fasted for forty days in 1879, and the painter Merlatti abstained from food for fifty days in 1886 at Paris; but these cases were not scientifically studied.

Succi is the classical type of professional faster. He has frequently fasted for twenty to thirty days at different times in Cairo, Milan, Paris, Florence, Rome, and in various cities in America. His fasts differ from those undertaken by others, in the fact that he is capable of doing without food for a long time, and yet remains in an almost physiological general state of health; in his case all the important functions, circulation, respiration, production and regulation of heat, muscular and nervous activity, and the sense of well-being, are maintained within normal limits.

According to Senator, Cetti also remained in perfect health during his ten days' fast, with the exception of the seventh day, when he suffered from colic, which ceased after the bowels had been emptied. The newspapers of the day relate that Tanner did not suffer appreciably from fasting until the seventeenth day, when giddiness, nausea, weakness, and cramp in the stomach set in, followed by vomiting and lowering of the temperature during the last days, so that many people thought he would lose his bet. In the case of Merlatti inanition took an abnormal course: after the first five days, during which he suffered from hunger, there was a long physiological period, followed by a third period of morbid conditions, during which threatening symptoms and a lowered temperature forced him to take to his bed.

V. The long fasts, which are accidental and unnatural in man and the higher animals, are the rule in plants and the lower animals. Insects, molluscs, reptiles, batrachians, and many fish spend the whole winter in a fasting condition. During this fast a state of almost total functional inactivity sets in, so that life appears to be suspended. This state of *minimal*, *almost latent* life is termed *hibernation*, and is quite distinct from *inanition*, during

which, as we have already seen, all the important functions are actively carried on, though in a less intense form than under ordinary normal conditions.

Even among the mammals, which are generally termed *warm-blooded*, there are many species which, when placed in a cold environment, do not maintain their usual temperature, but become as cold as reptiles, amphibians, and fish, and can bear this lowered temperature without injury; this low bodily temperature, which would prove fatal to most of the higher animals, only produces a more or less profound state of torpor. The term *hibernating* is applied to such animals, because regularly every winter they fall into a deep lethargic sleep or torpor.

The *torpor of hibernation* differs in degree. It is most profound in the small animals, such as the *bat*, *hedgehog*, *marmot*, *dormouse*, and *hamster*. *Brown bears* fall into a less sound sleep during the winter, but *white polar bears*, which are carnivorous, keep awake even in winter.

As a rule the hibernating mammals are represented by a group of animals which live on insects, fruits, or other similar foods in a country in which these foods are not procurable in winter. They therefore fast in winter, and fall into a state of torpor, curling themselves up in sheltered spots, and reducing all their functions, especially the combustion of material, to the lowest possible limit, so that they can live for a long time by consuming the fat which they accumulated during the favourable season. During torpor, breathing is suspended or very slow, one or two respirations in five minutes; the internal temperature falls to about 4° C. At long intervals they awake, come out to discharge their excreta, then return to their hiding-places and fall asleep again. Valentin noticed the interesting fact that the temperature rises when they awake.

It does not appear unlikely that the hibernating mammals have been evolved by a gradual process of adaptation to an environment which did not afford them food in winter. The animals which are unable to endure a reduction of respiration sufficient to enable them to live without food till the spring, either emigrate or die. The only ones to survive are those endowed with this capacity, which becomes greater and greater in their descendants.¹

Man under certain special conditions does not appear to be wholly devoid of this peculiar capacity of hibernating animals, the power to reduce his metabolic activities to such a degree that he becomes lethargic and remains in a fasting condition for a marvellously long time. This is said to be the case with the

¹ Another view is that hibernating mammals have retained in greater measure those characteristics of their cold-blooded ancestors which are found in all young mammals and birds. [Note by Editor.]

fakirs of India, who are supposed to throw themselves into a state of profound lethargy by hypnotic means. Similar phenomena have been noted in certain hysterical or psychopathic persons. Richet found in the case of hysterical patients at the Salpêtrière that pulmonary ventilation and the discharge of carbon dioxide gradually diminished during the lethargic state. Lethargy is therefore a genuine hibernation, which enables the patient to maintain a fast for a time proportional to the depression of the respiratory processes. The case of Anna Garbero, described by Dr. Asella (1827), and to which I referred in my monograph on fasting (1889), is one of very great interest. This woman lived in a state of lethargy, during which she was unable to take any food or drink for thirty-two months, eleven days! After this case the many marvellous stories of fasts collected from ancient literature and quoted by Fortunio Liceto, a lecturer at Padua early in the seventeenth century, in his book, *De his qui diu vivunt sine alimento*, will cease to appear so astounding as to make us class them one and all as fabulous and legendary.

We thus find that both animals and man can endure a long fast in two different ways: *inanition*, when all the functional activities are maintained at a level but little below the physiological, and the materials available for combustion are gradually consumed, so long as this is compatible with life; and *hibernation*, during which the liberation of energy is diminished, and thus the daily loss or combustion of material is reduced to a minimum. We can readily conceive of processes occupying a position between the extremes, inanition and hibernation, and partaking of the characteristics of either the one or the other.

Hibernation as a natural condition in hibernating animals is not associated with any noticeable suffering or morbid condition. Inanition, on the other hand, is not a natural state, and is associated with the sensation of hunger, and also of thirst, if there be abstinence from drink as well as from food. Hunger, however, only lasts three or four days and then disappears. This has been noticed in dogs, and was observed by myself in Succì, by Senator in Cetti and Breithaupt, and by Tigerstedt in the student on whom he tried the experiment of a short fast.

Analysing the condition, as observed in dogs, we can recognise three phases or periods in the process of inanition: the brief initial period of *hunger*; the long period of *physiological inanition*, characterised merely by a gradual diminution in the daily combustion and a corresponding diminution in the production of heat; finally, the period of *morbid inanition* or crisis, which precedes death, and during which there is a slight rise of temperature, vomiting, diarrhoea, and collapse.

No special change is found in the bodies of dogs which have died of inanition, with the exception of emaciation, wasting of the

muscles, a diminished capacity of the intestines, and a general anaemic condition of the nerve-centres. A marmot at the end of its winter sleep presents similar anatomical changes.

The total consumption of the organism during fasting, whether it be inanition or hibernation, is not equally distributed amongst the various tissues of which it is composed. This is clearly proved by the old experiments carried out upon pigeons by Chossat in 1843. Apart from small differences, Voit confirmed in 1866 these results in the case of cats. We will not reproduce the tables of results obtained by these and other experimenters, but will confine ourselves to remarking that the *relative consumption* is greatest in the adipose tissue (93 per cent); great in the spleen, the pancreas, the liver, and the blood (71-62 per cent); smaller in the striated and smooth muscles (43-34 per cent); still smaller in the excretory organs, such as the skin, the kidneys, and the lungs (32-22 per cent); small in the bones (17 per cent), and almost nothing in the nervous system (2 per cent). If, on the other hand, we consider the *absolute consumption*, i.e. the different shares taken in the total loss of weight by the different organs and tissues, the muscles and the adipose tissue lose by far the most in weight; next, at a considerable distance, follow the skin, the bones, the liver, the blood, and the intestines; last of all come the remaining organs, in which the loss of weight in relation to the total weight of the organism is so slight as to be almost negligible.

Neither the absolute nor the relative loss of weight produced in the tissues by starvation is a measure of the exchange of material which takes place within them. Were this the case, the nervous system would remain almost inert during starvation. Those tissues, then, which waste but little, live at the expense of the other tissues, which suffer more. The nervous system draws its nourishment from the blood, and the blood during fasting derives its nourishment in turn from the tissues which are more drawn upon for liquidation.

As a general statement it may be asserted that during fasting all the organs and tissues contribute their share towards the maintenance of the organism as a whole; but the organs which are of paramount importance for the continuation of life remain in a better condition of nutrition and lose relatively little in weight, for they make a greater use of this contribution for the requisite development of energy, and perform their functions at the expense of the other less important organs and tissues.

Even in the case of elements of one and the same tissue the younger live and multiply by karyokinesis (Bizzozero), while the older ones waste and are absorbed. A remarkable fact was discovered by Miescher (1880) with regard to Rhine salmon. When this fish makes its way from the salt water of the sea into the fresh water of the Rhine, it is in a state of perfect nutrition and its muscles

are highly developed. In fresh water it remains in a fasting condition for from six to nine-and-a-half months, and during this long period of inanition the muscles of the back become very much smaller, while the testicles and ovaries develop enormously. In this case, therefore, inanition acquires the importance of a genuine physiological function, having as its object the development of the sexual organs at the expense of the other tissues and the maintenance of the essential function of reproduction.

The general conclusion to be drawn from all investigations into fasting in animals and men is that there are two fundamental conditions, if life is to last for a long time without an external supply of food: (a) there must be a certain provision of oxidisable materials stored up in the organism before the fast begins; (b) a greater economy must be exercised in the absorption and consumption of these materials. In inanition life lasts for a shorter time because there is little economy, whereas in hibernation expenditure is reduced to a minimum, and life, therefore, lasts for an almost incredible length of time.

It is important to examine the course of the total consumption of the organism during fasting under conditions as far as possible uniform, in order to avoid the disturbances caused by variations in external temperature, muscular work, etc. For this purpose the curve of weight is constructed from the data collected carefully every day at some fixed hour after the bladder has been emptied. According to my own observations both in the case of dogs and of Succi, the course of the curve of weight during the long period of *physiological inanition* is extremely regular, and corresponds approximately to that of an equilateral hyperbole, the equation differing according to the individual and his initial weight. On the other hand, the curve deviates from the hyperbolic, and shows irregularities both during the initial period of hunger and during the final period of crisis which precedes death.

This fact proves that the organism possesses some mechanism which regulates the losses suffered daily during starvation. This is the mechanism which normally regulates the production and loss of heat, and we shall study it in the next chapter. So long as the curve of weight follows the regular hyperbolic course, the regulators are working well; when it deviates from this course, as during the periods of hunger and crisis, they work badly, finally fail, and thus bring about the death of the organism.

VI. For the determination of the quality and quantity of the material consumed daily during starvation, the quantitative analysis of the chemical products contained in the urine, and the carbon dioxide discharged from the lungs and skin, is as indispensable as in the case of ordinary nutrition. From the quantity of nitrogen we can deduce the quantity of protein consumed; from

the quantity of carbon we can find, after deducting the carbon of the protein consumed, the approximate quantity of fat, etc., consumed.

From the concordant results of the investigations so far made upon the metabolism during fasting, both of man and animals, we find that the protein consumption steadily decreases—at first rapidly, afterwards more slowly. On the other hand, the consumption of fat, if the man or animal has a good provision before the fast begins, does not vary much from the beginning to the end of the fast.

During Succi's thirty days' fast I found that the daily average consumption of protein was very small; this explains Succi's extraordinary power of fasting for long periods. On the first day of the fast the urine contained 13·8 grms. of nitrogen = 29·6 grms. of urea; on the tenth day the quantity fell to 6·7 grms. = 14·47 grms. of urea; on the twenty-ninth day it amounted to only 4 grms. = 8·74 grms. of urea.

If we compare these data with those obtained by Munk during Cetti's ten days' fast, we find that the average for the nitrogenous consumption was very much higher: on the first day 28 grms. of urea, on the tenth day 20 grms. If the proportion of this consumption to the body-weights of the fasting men be calculated, we find that on the first day Succi discharged 0·47 gm. of urea per kgrm. and Cetti 0·51 gm.; while on the tenth day Succi discharged 0·25 per kgrm. and Cetti 0·39 gm. These differences are due in great measure to the fact that Succi was a mature man well provided with fat, while Cetti was a thin youth and consequently could not economise the consumption of nitrogenous substances by burning his fat.

It is worthy of note that during the first three or four days of fasting, the nitrogen in the urine does not gradually decrease as is the case in the following days of inanition, but, on the contrary, increases somewhat. Thus in the five days' fast of a young student, Tigerstedt found the following amounts of nitrogen in the urine: first day, 12·17 grms.; second day, 12·85; third day, 13·61; fourth day, 13·69; fifth day, 11·47. This result is easily explained by the assumption that during the first days of fasting the glycogen stored up in the body is consumed more readily than the fat, thus effecting a great saving in the consumption of the protein. In proportion as the store of glycogen decreases, the quantity of nitrogen in the urine must increase, and the gradual diminution of nitrogen becomes noticeable only when all the glycogen has been consumed. Whilst an ample provision of fat in the person who is fasting economises the consumption of protein during the whole course of inanition, the store of glycogen only does so during the first few days.

The *sulphur* discharged during the fast in the form of alkaline

and earthy sulphates arises from the combustion of protein, and should therefore follow the same curve as that of the nitrogen. The fact that the two curves are not absolutely parallel is probably due to the two products not being eliminated as they are formed, but retained to a greater or smaller extent by the blood according to the degree of concentration of the plasma.

The discharge of *phosphorus* in the form of *phosphates* enables us to gauge the consumption during fasting of organic compounds of phosphorus (lecithin, nuclein, jecorine) and the phosphates of lime and magnesia in the bones. I myself in the case of Succi, and Munk in that of Cetti, found that there was a relative increase of phosphorus in proportion to the nitrogen. Munk found an increase of both lime and magnesia, thus proving that the bones also waste during fasting. I found further that the consumption of phosphorus compounds economised the consumption of nitrogen.

As regards the output of *chlorine*, *sodium*, and *potassium*, Munk found that during fasting there is a preponderance of potassium over sodium, whilst on an ordinary diet the reverse is the case, owing no doubt to the chloride of sodium with which the food is flavoured. The chlorine, as in general also the alkalis, decreases in the urine during fasting, and both are retained in large quantities in the organism during the first few days after food has been taken again, because of the deficiency of these substances in the tissues. This is a proof that they are real food substances, in the sense that they combine with the organic molecules of the tissues and become structural materials.

During the first days of nutrition after a long fast, the organism clearly shows a tendency to compensate itself for the losses it has suffered, by retaining a large quantity of protein, fat, water, and salts. The young student, whose five days' fast was studied by Tigerstedt, lost in that time 399 grms. of protein, 938 of fat, 3829 of water, and 37 of ash. In the two following days on an ample diet he retained 20 per cent of the protein, 36 per cent of the fat, 71 per cent of the water, and 69 per cent of the constituents corresponding to the ash lost during fasting.

It is a very remarkable fact that the consumption of material in the organism during fasting is not in proportion to the size and weight of the fasting animal. The consumption per unit of weight differs considerably in small and large animals; the smaller the animal, the greater is the consumption. If, on the other hand, we reckon the consumption per unit of body-surface instead of per unit of weight, we find, according to Bergmann and Rubner, that the consumption corresponds to the body-surface. This relation between consumption and body-surface is explained according to Rubner by loss of heat. In order that the temperature of the body may remain constant, as is the case in warm-blooded animals, the production of heat, and hence the organic

combustion, must be in proportion to the loss of heat as determined by the body-surface.

This simple explanation will, however, appear inadequate if we examine the phenomenon of the loss of heat more closely. As we shall see in the next chapter, this loss does not depend merely on the relative extent of the surface of the body, but also upon the external temperature, the thickness of the layer of adipose tissue, and the hair or clothing covering the skin. We must also bear in mind that in cold-blooded animals, the temperature of which is variable, the loss of heat is not proportional to the production, and, moreover, in these animals the consumption differs greatly in animals of different weights.

Voit accounted for this phenomenon by connecting it with the fact, proved by Vierordt, that the blood circulates more rapidly in small animals than in large ones, so that in the former the same portion of the organs is supplied during a given time with a more copious flow of blood than is the case in the latter. Voit considers that the more quickly the tissues are supplied with blood, the more intense will be the metabolism. This theory has, however, never been proved conclusively, nor does it afford an explanation of the metabolism of cold-blooded animals.

Hösslin suggested as an explanation of the greater metabolism of small as compared with large animals that the former are obliged to move more quickly than the latter in order to escape their enemies and to catch their prey. Now it is easy to prove that the work necessary for locomotion is proportional not to the size of the body, but to the square of its cube root. It has been found by experiment that the consumption per kgrm. of weight in dogs of different sizes traversing the same distance is in inverse proportion to the size of the animal. It follows that even in a state of rest small animals must consume more material per unit of weight. This teleological explanation does not, however, account for the condition in homothermic animals, nor does it hold good for poikilothermic ones.

We must also remember that *age*, *sex*, and *constitution* exercise an influence on the intensity of the combustion both in man and animals, though this influence is not so great as that of the size of the body. According to Magnus-Levy, the consumption per unit of body-surface in healthy individuals is as follows:

Males from 20 to 40 years of age	100
Adult women	113-117
Young women	115-135
Boys of 2½-12 years of age	137-160

The influence of the constitution is obvious if we compare the consumption of material in thin, muscular persons with that in stout people; it is much greater in the former than in the latter,

both in proportion to the unit of weight and to the unit of body-surface. Magnus-Levy found that a person of normal constitution weighing 83 kgrms. absorbed 297 c.c. of oxygen per minute, and a stout person weighing 100 kgrms. 307 c.c. per minute, that is, the former absorbed 3.6 c.c., the latter 2.8 c.c. per kgrm. (almost 25 per cent less). The former used 125 c.c., the latter 108 c.c. per square metre of surface. This difference proves that not the body-surface, but the *constitution* exercises the greatest influence on the intensity of combustion. It is a fact well known to every one that a too sedentary life is favourable to the accumulation of fat in the organism, whilst an active life and regular exercise develop the muscles and favour the consumption of fat. After such a constitutional change, there is an increase of about 10 per cent in the combustion. In dogs which have been for long trained to perform muscular work, a remarkable increase in the consumption of oxygen during rest has been observed, as compared with that found before such training.

VII. If an animal be kept fasting for several days and then fed, the metabolism which had gone down during the period of abstinence immediately increases, even if the quantity of food taken be very small. I proved this to be the case with Succi on the twenty-fifth and twenty-sixth days of his fast, by giving him small quantities of gelatine and peptone respectively.

It is not possible to preserve the organism in the state of nutrition obtaining after a fast lasting several days, by giving it a supply of food, both nitrogenous and non-nitrogenous, corresponding to the daily loss of nitrogen and carbon. Each time food is given the metabolism of the tissues is stimulated to greater activity, so that the organism consumes more than when fasting, the output is therefore greater than the intake, and the weight of the body decreases, though more slowly than during absolute fasting. If we increase the nourishment gradually, the difference between the intake and output will diminish, at first more rapidly, afterwards more slowly, and finally attain an almost perfect equilibrium. This equilibrium is reached when about twice or three times as much nitrogen and about one-and-a-half times as much carbon are given in the food as the animal lost daily during its fast.

If a dog be kept for several days on a meagre diet of nitrogenous food, such as lean horse-flesh, so that there is a deficit in the daily balance of nitrogen, and is then given enough nitrogen to make up for the losses sustained, there is for some days a gain in the balance of nitrogen, that is, the intake of nitrogen will exceed the output. This gain will, however, gradually diminish, until in a few days nitrogenous equilibrium is attained; *i.e.* the meat consumed is equal to that received.

If the animal in a state of equilibrium on a plentiful meat

diet be given a relatively scanty diet of meat, a deficit in the nitrogen will be noted for some days, but will gradually diminish, until a fresh state of equilibrium between the nitrogenous intake and output is attained. A clear example of this phenomenon is afforded by the following table of the results obtained by Voit with a dog weighing 33 kgrms.:

Successive Days.	Daily Intake of Nitrogen in Grms.	Daily Output of Nitrogen in Grms.	Daily Balance of Nitrogen in Grms.
1	17.0	18.6	- 1.6
2	51.0	41.6	+ 9.4
3	51.0	44.5	+ 6.5
4	51.0	47.3	+ 3.7
5	51.0	47.9	+ 3.1
6	51.0	49.0	+ 2.0
7	51.0	49.3	+ 1.7
8	51.0	51.0	0
Sum Total retained . .			+ 26.4

Successive Days.	Daily Intake of Nitrogen in Grms.	Daily Output of Nitrogen in Grms.	Daily Balance of Nitrogen in Grms.
1	51.0	51.0	0
2	34.0	39.2	- 5.2
3	34.0	36.9	- 2.9
4	34.0	37.0	- 3.0
5	34.0	36.7	- 2.7
6	34.0	34.9	- 0.9
7	34.0	34.0	0
Sum Total lost . .			- 14.7

The first table proves that on the seventh day of the abundant diet of meat, nitrogenous equilibrium was obtained after the animal had retained 26.4 grms. of nitrogen in the form of protein; the second table that when the change was made from this plentiful diet to a scanty diet of meat, the equilibrium of nitrogen was also obtained after the animal had lost an amount of flesh corresponding to 14.7 grms. of nitrogen.

We may therefore conclude that it is generally possible to obtain *nitrogenous equilibrium* if a carnivorous animal be kept on a purely meat diet *differing considerably in quantity* for a certain number of days. There is, however, a maximum and minimum limit to the daily amount of meat given, beyond which it is impossible to obtain the equilibrium between the intake and output of nitrogen. The maximum quantity of meat for the attainment of this equilibrium is fixed by the digestive capacity of

the alimentary canal for meat; the minimum by the quantity of flesh and fat of the animal, *i.e.* by the state of nutrition of the animal before beginning the purely meat diet.

In the case of the dog weighing 33 kgrms., Voit obtained the maximum limit for the nitrogenous equilibrium with 2500 grms. of meat per day; with 2600 grms. there was a gain in the balance; with 2900 grms. there was a deficit, caused by indigestion, diarrhoea, sickness, discharge of undigested meat in the faeces. In the same dog Voit found 480 grms. of meat insufficient for the attainment of nitrogenous equilibrium. Only after a fast of eleven days was this quantity of meat sufficient to give equilibrium between the intake and output. Thus the limits of equilibrium in the said dog extended from 2500 to 480 grms. of meat per day, that is, from 85 to 16 grms. of nitrogen.

The state of nitrogenous equilibrium, although unstable and subject to slight variations, may continue for a considerable time on a medium diet of meat, provided there are no disturbances of metabolism due to external or internal causes, such as marked variations in the surrounding temperature, muscular and nervous activity differing very much in degree on the successive days of the experiment. When, on the other hand, the quantity of animal food reaches or approaches the maximum or minimum limit, the nitrogenous equilibrium is easily disturbed, and the animal cannot live for any length of time.

Munk and Rosenheim fed a dog on a meagre quantity of meat, which was, however, sufficient for nitrogenous equilibrium, and found that during the sixth to the eighth week grave disturbances took place, which caused the death of the animal in the course of a few weeks. Jägerroos was, however, able to keep a dog alive much longer under similar conditions, by giving it *fresh, raw meat*. It is therefore possible that in Munk's experiment illness and death were not brought about by a too scanty diet and consequent exhaustion from a slow process of inanition, but by other causes connected with the quality of the food or other disturbing extrinsic or intrinsic conditions.

If we determine, in addition to the nitrogenous exchange, the intake and output of carbon, we can also find out whether fat is consumed or stored in the body on a purely meat diet. According as the output of carbon is in excess of or less than the intake, we may conclude that fat is consumed or formed.

The experiments made by Pettenkofer and Voit proved that if only a small quantity of meat be given, the animal loses both flesh and fat; if the quantity given be increased, the loss of both flesh and fat will diminish, and there will be tendency towards equilibrium in both; if the amount of meat given be again increased, the consumption will increase until nitrogenous equilibrium is reached, whilst carbon is retained for the formation

of fat. This formation of fat is not however very great, and never exceeds 4-12 per cent of the meat consumed, calculated in the dry state.

The quantity of fat formed on a purely meat diet does not in Voit's opinion depend only on the quantity of meat taken, but also on the quantity of fat possessed by the animal. A lavish meat diet adds to the amount of fat when the animal is lacking in fat owing to a previous fast of long duration; when, however, the animal has a good deposit of adipose tissue, such a diet not only does not add to it, but causes it to be consumed.

We have already dealt with the complex *question of the formation of fat* in Vol. II. Chap. V. 12, to which we refer the reader.

What we have said as to the effects of a purely meat diet on the metabolism of dogs applies to all carnivorous animals, but is not wholly applicable to man, who is omnivorous, still less to herbivorous and frugivorous animals. Man, who interests us most, cannot tolerate for any length of time a purely meat diet, whether it be small or large. Ranke tried the effect on himself of an abundant diet of meat for two successive days. His weight being 73 kgrms., he took on the first day 1832 grms. of meat, and found that he could only digest and utilise 1300 grms.; on the second day the amount taken was 2000 grms. and that consumed only 1089 grms. This and other observations led him to the conclusion that man in general is able to tolerate a smaller quantity of meat than a carnivorous animal weighing only half as much. This is undoubtedly due to his limited power of digesting protein foods.

VIII. There has never been any question as to the nutritive value of fats and carbohydrates, but actual investigations as to the effect of these non-nitrogenous substances on the exchange of material were only begun at the time when Pettenkofer and Voit were putting into practice their methods of investigating the balance of nitrogen and carbon.

A fundamental difference is observed when the effects of a diet consisting exclusively of substances containing nitrogen are compared with those of a diet composed wholly of substances devoid of nitrogen, such as fats and carbohydrates. Whereas, in the former case, it is possible, as we have already seen, under suitable conditions to obtain and maintain for a considerable time in carnivorous animals the equilibrium between the intake and output, in the second case, even when the diet is abundant, this equilibrium is never attained; the consumption of protein substances never entirely ceases, so that the tissues of the organism are gradually consumed through inanition, which ends in death, just as does absolute abstinence from food, the only difference being that the process takes longer. Both groups of the non-

nitrogenous food-stuffs have the same effect when no other food is given.

On a diet consisting only of fat there is no saving in the consumption of the protein of the organism, since the quantity of nitrogen contained in the urine remains the same, and even increases if too large a quantity of fat be given to the animal after a period of fasting. The consumption of fat steadily increases, but the whole of the fat eaten is not always burnt, and part of the fat stored up in the organism is spared, which fact explains why death from inanition does not take place so quickly as when the fast is absolute. These facts are clearly proved by the researches carried out by Frerichs and Voit, as will be seen by the following tables :

Days of Research.	Diet of Fat in Grms.	Output of Nitrogen in Grms.	Consumption of Fat in Grms.
1	0	6.0	111
2	0	5.2	86
3	100	5.4	97
4	100	4.5	103
			98
			100
1	0	11.6	97
2	0	5.7	107
3	0	4.7	102
4	350	7.7	169
			102

Likewise a diet consisting exclusively of saccharides, starch, cane sugar, grape sugar, milk sugar, does not diminish the consumption of nitrogen below the amount which obtained previously when the animal was in a fasting condition : it remains unchanged, and does not increase—as sometimes happens in the case of a diet of fat—when the quantity given is increased. Inanition and death cannot be prevented if the diet consists wholly of carbohydrates, though they may be postponed longer than in the case of an absolute fast (Frerichs). The nutritive value of fats and saccharides and the different way in which they act upon metabolism can be deduced from the results of the experiments in which fats or saccharides are added to the meat or general protein diet.

If fat be added to the diet of meat, the consumption of protein does not fall, when compared with that seen previously in a fasting condition ; if, however, this diet be continued for a number of days, the animal will accumulate fat, and in proportion to its increase of fat will be the diminution in the quantity of flesh consumed. Thus fat added to the protein diet saves the consumption of flesh indirectly, that is, by fattening the animal. When carbohydrates

are added to the diet of meat the protein consumption diminishes; with the addition of this food-stuff the animal can preserve its store of flesh, and increase this reserve on a smaller amount of meat. The saving in the consumption of flesh brought about by saccharides is greater than that caused by an equal quantity of fat. This explains why herbivorous animals put on flesh quickly when their food contains a large quantity of carbohydrate.

There is a minimum limit to the amount of meat which in conjunction with saccharides must be taken in order to maintain nitrogenous equilibrium; if this limit is not reached the animal will lose flesh. The limit is lower in fat non-fleshy organisms, higher in lean fleshy organisms.

Carbohydrates not only effect a saving in the consumption of flesh, but also in the consumption of fat, and therefore increase the amount of fat in the body (Voit).

Liebig, taking into consideration the well-known fact that animals (pigs, geese) which are to be fattened are given large quantities of carbohydrate and only small quantities of protein, was the first to propound the theory that saccharides are transformed into fats. Against this theory Voit set up that of sparing, according to which the increase of fat is due to the fact that the saccharides lessen the combustion of fats, which therefore accumulate in the organism. We have, however, in the treatment of the complex subject of the formation of fat, shown the correctness of Liebig's theory according to the successive investigations of Munk, Tscherwinsky, Meissel and Strohmer, and of Rubner (*vide* Vol. II. Chap. V. 12).

It is necessary to lay stress upon the fact that saccharides are more readily decomposed than fat, either taken in as food or stored up in the body. When a little starch or sugar is added to an abundant diet of meat, an increase in the quantity of carbon dioxide discharged by the animal is immediately observed; when, on the other hand, fat is added, there is no change in the quantity of carbon dioxide discharged (Voit). If a fasting dog be given a certain amount of carbohydrate after the value of its respiratory quotient has been ascertained and time allowed for intestinal absorption, we shall find an increase in the respiratory quotient, which proves the rapid oxidation of the food given (Magnus-Levy).

The calorimetrical researches made by Atwater, of which we shall treat in the next chapter, not only confirm the theory that saccharides are easily oxidised, but prove that with a mixed diet which contains a large quantity of saccharides, these substances are the first to burn, the combustion of the fats contained in it only beginning when the saccharides have been entirely consumed.

IX. We must now ascertain the value as regards metabolism of

certain other organic substances, some of which are formed during the process of digestion in the alimentary canal, while others are almost always found mingled with our food. Albumoses, peptones, amino-acids, fatty acids, and glycerine belong to the former class; gelatine, alcoholic beverages, and the so-called condiments to the latter.

(a) In the course of our study of the chemical processes of digestion, both gastric and intestinal (Vol. II. Chaps. III. and IV.), we saw that protein substances are resolved into many different products, *protoalbumose*, *deuteroalbumose*, *hemipeptones*, *antipeptones*, *amino-acids*. It will now be of interest to ascertain the nutritive values of these substances in relation to their different chemical constitution.

The first researches undertaken by Plosz, Maly, Adamkiewicz (1874-77-78) were made with the so-called *peptone* of commerce, which is a mixture of the different products of protein digestion. These researches, however, seem to prove that this compound of different digestive products is of the same nutritive value as the genuine protein of the ordinary diet. For instance, Adamkiewicz gave to a fasting dog, which weighed about 20 kgrms., and was losing on an average 3.75 grms. of nitrogen per day, 50 grms. of peptone containing 7.75 of nitrogen, and the animal discharged an average of 8.52 grms. of nitrogen. When 100 grms. of fat were added to the peptone, it only discharged 5.74 grms. of nitrogen, so that the intake and output of nitrogen were almost equal.

Pollitzer (1885) in his researches made use of *amphopeptone*, *protoalbumose*, and *deuteroalbumose*, isolated according to Kühne's method, and found that all these three products are of the same nutritive value as a corresponding quantity of meat, as will be seen from the following table :

Food-stuff.	Intake of Nitrogen in Grms.	Output of Nitrogen in Grms.	Daily Balance of Nitrogen in Grms.
Meat	2.41	1.91	+0.50
Peptone	2.41	1.83	+0.58
Meat	2.41	1.90	+0.51
Protoalbumose	2.47	1.80	+0.67
Heteroalbumose	2.49	1.67	+0.82
Meat	2.13	1.67	+0.46

Ellinger in 1896 investigated the nutritive value of the mixture resulting from the digestion of the pancreas (*glandular peptone*), which Kühne considers to be composed mainly of *anti-peptone*, but which contains other final products of digestion, and confirmed the results obtained by Pollitzer.

The more recent researches made by Blum in 1900 were

carried out with better defined products. He obtained the results shown in the following table :

Food-stuff.	Daily Intake of Nitrogen in Grms.	Daily Output of Nitrogen in Grms.	Balance of Nitrogen in Grms.
Meat	14.12	13.81	+0.31
Heteroalbumose of fibrin . .	14.12	15.30	-1.18
Meat	14.7	14.80	-0.10
Protoalbumose I of casein . .	14.7	14.43	+0.27
Meat	14.7	14.0	+0.7
Protoalbumose II of casein . .	14.7	14.4	+0.3

These results show that while the two protoalbumoses afford a perfect substitute for meat, this is not the case with heteroalbumose. According to Blum this difference is due to the absence in the heteroalbumose of those molecular groups necessary for assimilation which are found in the protoalbumoses, groups probably represented by indol. These compounds are, as a matter of fact, poorly represented in heteroalbumose, in which, on the other hand, the glyocol groups abound. At the same time the researches of Henriques and Hansen have shown that in mice heteroalbumose not only economises the consumption of albumen, but may even be substituted for it altogether.

(b) Gelatine which, as is well known, is obtained by boiling down the connective tissues (Papin, 1682) is a modification of albuminous substances which, when cold, forms a hydrogel, which can be peptonised like albumens. Its nutritive value has been much discussed.

At the time of the French Revolution the method of extracting gelatine was perfected with a view to improving the nutrition of both troops and populace, and it was looked upon as most nutritious, a committee of the Institut de France having declared it to be so. Gelatine soups were consequently given to hospital patients, but experience made doctors abandon their use, as they produced nausea.

In 1831, Donné made experiments with gelatine on himself and on dogs, giving the dogs 20-50 grms. of gelatine and 85-100 grms. of bread per day. He found that the dogs wasted away, but this was clearly due to their food being insufficient. Edward and Balzac also observed that dogs fed on gelatine wasted away, but they found that this was less noticeable when bread was added to the diet of gelatine.

In 1841 the French Academy appointed another committee to settle the disputed point. Magendie, who drew up its report, came to the conclusion that dogs cannot be fed on gelatine; that they will waste away even when bread and meat are given in

addition to the gelatine. Gelatine therefore is not only useless, but harmful, since it disturbs the digestion.

Frerichs and Mulder (1843) called in question the experiments made by the French commission and Magendie, and proved that gelatine cannot be substituted for protein, but that it economises the consumption of protein just as do sugar and fats.

In order to decide the matter, the balance of nitrogen in the dogs under experiment had to be ascertained; this was first done by Bischoff and Voit in 1860. They found that the whole of the nitrogen contained in the gelatine taken was eliminated in the urine. Gelatine, therefore, decomposes readily, and on the same day. Even when large quantities of it are given, the quantity of nitrogen in the urine is always larger than that in the gelatine taken, hence it cannot be regarded as a substitute for genuine albumens. If it be added to a diet of meat, it economises its consumption to a greater degree than fats and saccharides will do. It cannot be built up, but it burns readily, better than fats and sugars.

If animals be fed on raw collagenous tissues, bones, cartilages, tendons, connective tissues, it will be found that, while most of these substances are digested, they cannot take the place of protein substances properly so-called, although they economise the consumption of such substances. Hence the inability of gelatine to act as a building-up food is due to its molecular constitution and not to the chemical change undergone by the nitrogenous components of the tissues from which it is extracted during the process of boiling.

Voit and Pettenkofer (1872) considered that gelatine may also effect an economy in the consumption of the fat of the body, though to a smaller extent than saccharides and fats taken in food. The addition of gelatine to a lavish diet of meat causes an increase not only in flesh but also in the deposit of fat. The above-mentioned authors think, however, that this increase in fat is due to formation from proteins, not from the gelatine taken.

The decomposition of the gelatine eaten is brought about by the tissues, probably by the enzymes which they contain or produce during their metabolic activity. During my experiments on long fasts, both in Succi and in dogs, I found that gelatine decomposed slowly—in four to five days—and not on the same day, possibly because the enzymes decreased as the result of inanition. This decrease in the enzymes would also explain the fact that during inanition the discharge of nitrogen gradually decreases, *i.e.* the consumption of the albumens contained in the organs is economised.

Voit's researches into the nutritive value of gelatine were confirmed in all essential points by those made more recently by Oerum (1879), Pollitzer (1885), I. Munk (1894), and Kirchmann

(1900), and others. Oerum experimented for thirty-three successive days on a dog, alternating days of fasting with days on which he gave meat or gelatine. When he gave meat there was a gain in the balance of nitrogen; when he gave gelatine there was a *deficit*. This result is clearly shown by the following table:

Days.	Gelatine in Grms.	Meat in Grms.	Nitrogen given in Grms.	Nitrogen dis- charged in Grms.	Balance of Nitrogen in Grms.
1-3	...	...	...	2.1	- 2.1
4-8	...	91	3.5	3.2	+ 0.3
9-12	22	...	3.5	4.3	- 0.8
13-15	...	...	0.4	2.3	- 1.9
16-23	...	91	3.5	2.8	+ 0.7
24-29	22	...	3.5	3.9	- 0.9
30-33	...	...	0.4	1.7	- 1.3

The hydrolytic decomposition of gelatine into its component groups proves it to be lacking in cystine, tyrosin, and tryptophane. Kauffmann considers the inability of gelatine, and, in general, of the group of albuminoids properly so-called, to take the place of protein to be due to this defective chemical constitution. He experimented on himself and found it possible to preserve nitrogenous equilibrium if he substituted a mixture of gelatine, tyrosin, tryptophane, and cystine for the nutritive proteins. This result has however been contradicted by Bona and W. Müller, who found that the addition of tyrosin and tryptophane to gelatine did not effect any economy in the consumption of nitrogen. Further and more numerous researches are necessary before this question can be regarded as definitely settled.

(c) We know that during digestion in the stomach and intestines the neutral fats are resolved into free fatty acids and glycerine (Vol. II. Chapters III. and IV.). The nutritive value of neutral fats is the same as that of the fatty acids contained in them. This has been proved by numerous researches. I. Munk, for instance, obtained nitrogenous equilibrium in a dog by giving it 800 grms. of meat and 70 grms. of fat. The equilibrium remained unchanged when he substituted for the 70 grms. of fat the fatty acids extracted from that quantity of fat. He therefore concluded that fatty acids effect the same economy in the consumption of protein as the corresponding quantity of neutral fats would do. This fact will be easily understood if we reflect that fat contains only about 9 per cent of glycerine and that the heat of combustion of glycerine is about half that of fat. The substitution of the corresponding fatty acids for nutritive fats does not therefore produce a noticeably different effect on the organism.

If, on the other hand, a large quantity of glycerine (40-70

grms.) be introduced with the food, a good deal of it (about 30 per cent) will be discharged by the kidneys in an unchanged state, and the remainder burnt without causing any great increase in the quantity of carbon dioxide discharged; this suggests that glycerine probably effects a slight saving in the consumption of fat or albumen.

X. It is important to go briefly into the effect produced on metabolism by the alcoholic drinks which are unfortunately almost always taken apart from meals and by the lower classes both with and between meals. The main ingredient of all fermented drinks, such as wine, beer, brandy, and liqueurs, is alcohol, which is readily absorbed as such, so that it can be distilled from the blood. In the body it is burnt, though not as quickly and entirely as was thought by Liebig. A small portion is exhaled through the lungs, amyl alcohol in larger quantities than ethyl, according to Binz; another portion is discharged undecomposed in the urine (Sieben); the largest portion (98 per cent as a mean according to Atwater) undergoes combustion and is transformed into water and carbon dioxide, developing a certain amount of heat, and therefore serves as combustible material.

The researches of Zuntz and Berdez (1887), as well as those made at the same time by Geppert, show that alcohol taken in non-toxic quantities does not cause an increase in the quantity of oxygen absorbed or in the amount of carbon dioxide discharged. We must, then, conclude that the combustion of alcohol effects an economy in the consumption of nitrogenous or non-nitrogenous substances.

The experiments made by Fokker and I. Munk on dogs, when nitrogenous equilibrium had been obtained, showed that alcohol in moderate quantities effected an economy of about 6-7 per cent in the consumption of nitrogen, whereas in quantities, sufficiently large to produce intoxication, it increased this consumption by 4-10 per cent. In the former case, according to the researches made by Bock and Brauer, the gaseous respiratory exchange is slightly depressed, while in the latter case it is of course increased. The slight decrease in the discharge of carbon dioxide when the quantities are moderate cannot be due only to economy in the consumption of protein, but must also be due to the sparing of non-nitrogenous substances. The increase in the carbon dioxide when large quantities are taken arises not only from the increased amount of nitrogen consumed, but also from the consumption of fat.

The more recent experiments upon man made in 1902 by Atwater and Benedict, who determined directly the total exchange of material and the loss of heat, also go to prove that alcohol during combustion can take the place of articles of food not

containing nitrogen, and therefore we cannot deny that it is of a certain nutritive value.

From the practical point of view, however, the nutritive value of alcohol is in the prevalent opinion of the greatest clinical authorities of the present day counterbalanced by the injurious effects produced by its daily use even in moderate quantities.

Of the different alcoholic beverages wine is the least injurious in its effects upon the physique and morals of the people. Taken in moderation, it induces a subjective sense of warmth through a slight depression in the tone of the blood-vessels and diminishes the sensation of fatigue. It degrades, however, the physical, intellectual, and moral strength.

The nutritive quality of beer has gained it much approval, containing, as it does, about 6-8 per cent of dextrin, sugar, and vegetable albumen in addition to alcohol, the alcohol being mainly amylic. The use of beer, however, tends to produce heaviness of both mind and body to a greater extent than does wine, an effect which is often noticeable in the people of northern nations who drink large quantities of beer.

Spirits produced by the fermentation and distillation of cereals and potatoes are the most common drink of the working man in northern lands. These spirits are much more injurious than beer, at the same time supplying less heat and costing more than the cereals used in their manufacture. On physiological grounds no excuse can be offered for the use of spirits, but from the psychological point of view it may be advanced that the working man receives a sensation of warmth and an apparent decrease of fatigue. But spirits may be readily abused, and their use should be opposed on philanthropic grounds.

Meat broth is largely used as a restorative both for the sick and those in good health. Liebig's extract is merely meat broth condensed till it is nearly dry. When the meat is boiled the proteins contained in it coagulate and remain in the cooked meat, while the extractives dissolve, together with part of the proteins which had already coagulated. The dissolved nitrogenous substances are represented by proteose or albumose, peptones, soluble albumen, gelatine, creatin, creatinine, carnin, etc.; the non-nitrogenous substances by inosit, sugar, lactic acid; the salts by potassium phosphate and sodium chloride.

The presumed restorative quality of broth is certainly not due to the nutritive elements it contains, for they are extremely few, but rather to its stimulating effect on the central nervous system, making it less liable to feel the need of food, by taking away or lessening the sensation of hunger. There is no component of meat extract of such nutritive value, either by reason of its quantity or its chemical properties, as to explain the restorative effect commonly attributed to broth. Bunge remarks with

reference to the effect of meat extract that "we know nothing about it except that its taste and smell render it palatable to every one. This in itself would entitle it to rank as the best condiment for dishes; another reason being that it is never taken to excess."

Other pleasant beverages which are rarely abused are tea and coffee. Like meat broth, they clearly have a stimulating effect on the nervous system and also on the muscular system. They contain *caffein* and *thein*, which are chemically closely related to *xanthine*, a catabolic product of the tissues containing nitrogen. The chemical composition of *caffein* places it among the *trimethylxanthines*. It is mostly decomposed by the tissues; only in cases where very large quantities are taken (50 centigrms.) does a part appear in the urine in a non-decomposed state. It has no noticeable effect on metabolism; Voit found that the nitrogen in the urine neither increased nor decreased. In addition to the alkaloid, tea and coffee contain aromatic substances and ethereal oils; this fact explains their general effect on taste and their somewhat different actions as stimulants. Tea further contains 3.03 per cent of salts, salts of iron, sodium, and manganese; coffee, on the other hand, contains more salts of potassium.

The seeds of the cocoa plant, from which chocolate is made, contain theobromine, which is a dimethylxanthine. Cocoa is not merely a pleasing beverage, but also a real food, containing about 50 per cent of fat and 12 per cent of albumen. There is no substance which contains a larger amount of nourishment in such a small volume and weight. It is, therefore, a most convenient form of provision for journeys, marches, and rapid military movements.

Spices, such as pepper, cinnamon, cloves, nutmeg, ginger, and mustard, are condiments pure and simple, having no direct effect on the exchange of material; they are, however, pleasing to both taste and smell, and stimulate through the nervous system the secretions of the organs both of vegetative and animal life. Their abuse is harmful, but when taken in small quantities they are useful.

The use of tobacco, which is so common, produces an effect much like that of spices, but may very easily be abused. Clinical and anatomical - pathological experience show that chronic nicotine poisoning favours the development of arterio-sclerosis, catarrh of the pharynx, arrhythmia of the heart, and attacks of angina pectoris.

The scents of flowers and of certain animal secretions and perfumes in general excite the olfactory sense and stimulate nervous and psychical activity.

As a general rule, it may be said that condiments, spices, and scents are no less necessary to man than the true foods, which in

some cases, having neither smell nor flavour, have no effect on the sense of taste and smell. These are especially the senses which evoke the digestive secretions and stimulate the whole nervous system. Man does not live on food alone; the pleasures of the senses in moderation are necessary factors in his well-being, in his physical and psysical life.

XI. Inorganic aliments, such as water and mineral salts, are just as necessary to normal metabolism as the organic.

A large quantity of water is being lost continually through the kidneys, lungs, and skin. It amounts on an average to about two kgrms. daily or 3 per cent of the weight of the body, when the individual is in a state of rest and the equilibrium between the intake and output of material is undisturbed, but is largely increased during the performance of hard work. Water is therefore a most important factor in the exchange of material.

Life without water or an adequate supply of water is impossible. Thirst is more difficult to endure than hunger arising from absolute deprivation of food. Disorders of the most serious kind begin when the organism has lost 11 per cent of water, whereas death from inanition only takes place after a decrease in weight of 40 per cent. When water is taken in quantities larger than are necessary to cover the deficit, the surplus is eliminated mainly by the kidneys, and with the water is discharged an increased quantity usually about 3-5 per cent of the nitrogenous products of combustion. When the water in the urine is three to six times the normal average, the increase in the nitrogen contained in it may be as much as 10 per cent. Thus if the current of water passing through the organism be increased, the tissues are cleansed from the nitrogenous products which they contain, and the expulsion of urea from the circulating fluids is facilitated (Voit), or the formation of it by the liver is increased, *i.e.* the consumption of protein is increased (Bidder, Schmidt, J. Meyer).

This increase in the consumption of nitrogen, caused by the intake and discharge of very large quantities of water, persists in animals which are fasting (Forster); whereas in animals which are being fed it is merely transitory, and when the normal has been reached it persists even if an excessive quantity of water still be given (Neumann).

Örtel's researches showed that the quantity of water introduced into the organism also affected the accumulation and consumption of fat in the body. When the loss of water in the excretions is increased, when a smaller quantity is drunk, or, better still, when the output is increased and the intake diminished at the same time, it is always found that the fat accumulated in the body decreases. This phenomenon has not yet been adequately explained, but, if it is a fact, it becomes of practical importance in the cure of *obesity*.

With the ordinary nutritive substances, a considerable quantity of mineral compounds are introduced into the organism. They are obviously necessary during the *anaplastic period* for the formation of the bones and tissues. Since the child at the breast grows and lives solely on his mother's milk, it is clear that this food must contain everything which is necessary for the development of the child.

The ashes of milk are, according to Bunge, almost identical in quality and quantity with these which can be extracted from the organism of the sucking child. The former contain rather more potassium and less sodium than the latter. This is due to the development of the muscles, which contain more potassium, and to the gradual ossification of the cartilages, which contain more sodium. Chlorine is also found in larger quantities in the ashes of the milk than in those of the infant, possibly because chlorides are used in the formation of the acid of the gastric juice, and are not all absorbed when they pass into the intestines, and of those absorbed a part is discharged by the kidneys.

When the child is weaned, does it find in other articles of food, as it did in milk, the salts which are necessary for its growth? The composition of the ashes of the principal articles of food shows that they contain in an even greater proportion all the mineral elements found in milk, with the exception of calcium, of which there is a small quantity as compared with that found in milk. Yolk of egg is the only food which contains a larger quantity of calcium than milk; it is therefore the best substitute for milk which can be given to children.

Cow's milk contains more salts than human milk; this is accounted for on teleological grounds by the fact that the calf grows more rapidly than the child. From this point of view the adult organism, once the anaplastic period is over, should not need to take in mineral substances which, being saturated compounds and possessing no potential energy, are not consumed during the metabolism of the tissues. We must, however, bear in mind that mineral substances are chemically combined with organic substances, and when these latter are decomposed, the salts remain free, and since they are not—or only in part—employed in the formation of new organic complex molecules, they diffuse in the fluids and are discharged in the excretions. They are indeed eliminated in large quantities even when the body is in an absolutely fasting condition. This explains why it is necessary for adults to take constantly fresh mineral substances with their food.

Forster in 1873 fed two dogs on the residue of meat from which Liebig's extract had been made; these residues, washed in distilled water and dried, contain only 0·8 per cent of salts. To these proteins containing very little salt he added fat, sugar, and starch,

so as to form an adequate mixed diet; the dogs wasted steadily away; one of them was at the point of death from exhaustion on the thirty-sixth day, the other reached the same stage ten days sooner; yet we know that dogs which are entirely deprived of food can live considerably longer. Forster also fed three pigeons on starch and casein, which contains a very small quantity of salts; on this diet they lived only thirteen, twenty-five, and twenty-nine days respectively.

Bunge considers that the brief duration of life, when there are not enough salts in the food, is due to the formation from the proteins of sulphuric acid which, failing to find in the blood the bases with which to saturate itself, attacks the bases of the tissues and thus hastens their consumption.

Lunin (1881) showed by special researches the probability of this explanation. He fed a number of mice on food almost entirely devoid of salts. He precipitated the casein and fat from cow's milk with acetic acid and then washed it until it contained only 0.05-0.08 per cent of salts, *i.e.* 10 per cent less than in Forster's casein; he added to this casein cane sugar and distilled water, and found that the mice on this diet lived only eleven to twenty-one days. When he added to this diet enough carbonate of soda to neutralise the sulphuric acid formed, the mice lived longer, sixteen to thirty days. When, on the other hand, he added sodium chloride, *i.e.* a neutral salt incapable of neutralising the acid, the mice lived about the same length of time as those in the first series. But even when the sulphuric acid formed was neutralised the mice did not live long on a diet devoid of salts. Further, when Lunin added the ashes of milk to the purified casein, the mice did not live longer than when only carbonate of soda was added, whereas it is well known that mice can live for an indefinite period on nothing but milk. The most probable explanation of these results is that salts taken as such are not perfectly assimilated; apparently they must be combined with the protein of the food.

This hypothesis is not, however, applicable to salts of iron, which can be assimilated as such, although in common articles of food they are found chemically associated with protein molecules. This was proved by the interesting researches made by Coppola in 1890. He fed four cocks with a diet almost entirely devoid of iron, consisting of a paste composed of 30 grms. of starch, 2 of white of egg, 5 of gelatine, 4 of cane sugar, 0.70 of sodium carbonate, 0.40 of sodium chloride, 0.30 of potassium phosphate, 0.15 of calcium phosphate, and 0.15 grms. of magnesium phosphate. He found that on this diet, which was almost devoid of iron (0.11 milligrms. of iron per day contained in the gelatine), the cocks continually eliminated iron in the urine and faeces; the erythrocytes in the blood gradually became paler owing to the decreased quantity of haemoglobin without, however, decreasing in number,

whilst the leucocytes and microcytes increased. When 0.025 grm. of lactate of iron are added daily to the above diet, it is retained in a greater or smaller quantity according to the impoverishment which has already taken place, and the haemoglobin is renewed at the same time.

These results were confirmed in the case of dogs by the experiments of Lo Monaco in the Physiological Laboratory in Florence, of which I was director at the time; but while they show that inorganic salts of iron can be assimilated, the results of other experiments tend to prove that the iron contained in organic compounds can be assimilated even more readily than inorganic iron.

The facts we have enumerated afford incontestable proof that salts must be contained in a perfect diet for adults; they are, indeed, present in sufficient quantities in and combined with the ordinary protein foods.

To this rule sodium chloride is an exception; it is the only salt which it is customary to add intentionally to an ordinary mixed diet, although in such a diet it is already present in the organic food substances of vegetable or animal origin.

Bunge (1874) noticed that carnivorous animals dislike and, indeed, are disgusted by food to which salt has been added, whereas herbivorous animals, both wild and domesticated, devour such food greedily and will lick salt rocks and deposits, so much so that hunters employ salt in order to attract them. The explanation of this is, in Bunge's opinion, to be found in the fact that vegetable foods contain four or five times as much potassium as animal foods and therefore make herbivorous animals crave for sodium chloride. He noticed that nomad peoples who live entirely on the produce of the chase and fishing do not use salt in cooking, whereas races whose diet is largely vegetarian look upon it as indispensable. Rice-eaters are an exception to this rule: the Bedouin tribes of the Arabian peninsula do not add salt to the rice which is almost their only article of diet, because rice is poor both in potassium and sodium, a fact which goes to confirm the rule.

The sodium chloride contained in the blood is necessary for the formation of the hydrochloric acid in the gastric juice, the dissolving of globulin in order to facilitate intestinal absorption and the regulation of osmotic pressure and the isotony of the fluids, etc. When a salt of potassium, such as the carbonate, is dissolved in water together with sodium chloride, a partial exchange of the acids takes place, resulting in the formation of chloride of potassium and carbonate of soda. The same twofold decomposition must take place in the plasma of the blood, which always contains chloride of soda, when a very large quantity of carbonate of potassium is taken. The new salts which are formed,

being extraneous to the plasma, are eliminated by the kidneys, thus causing an increase in the potassium and sodium in the urine. Hence the blood becomes poorer in chlorine and in sodium, and the necessity arises for the addition of sodium chloride to vegetable foods.

It has been objected to Bunge's doctrine that certain negro tribes in Africa use the *salt of ashes* instead of ordinary cooking salt; this so-called *salt of ashes* is obtained by reducing certain plants to ashes and treating them in such a way as to deprive them almost entirely of alkaline carbonates, so that what remains is composed almost entirely of chloride of potassium with a small quantity of chloride of sodium. It tastes much like ordinary cooking salt; the negroes are extremely fond of it and prefer it to ordinary salt. Without accepting Bunge's theory as absolutely correct, we can still hold that the excess of potassium salts introduced takes with it during elimination by the kidneys sodium chloride from the plasma, and thus induces this need for the addition of salt to the food (Zuntz).

There is a larger quantity of potassium than sodium in the milk of herbivorous animals, and also in human milk, a fact which shows that a slight preponderance of potassium in the food is allowable. In meadow hay there is also only a slight preponderance of potassium, and this accounts for herbivorous animals, such as rabbits and hares, eating it readily without the addition of salt. A diet consisting only of vegetables which contain a large quantity of potassium, such as clover, affords an example of the need of salt. Herbivorous domestic animals which feed on such plants improve in condition if given rock salt, and suffer if they are deprived of it.

Man can live on a vegetarian diet without salt, if he avoids those foods which contain a great deal of potassium, such as potatoes, rye, peas, and beans. Country people use much more salt than townsfolk, in France three times as much, because they live mainly on potatoes and vegetables, whereas the inhabitants of towns take more bread, wine, and meat.

As a general rule, the evidence shows that there is generally an excessive use of cooking salt, more undoubtedly than is strictly necessary; it serves at the same time as a *condiment*, giving flavour to the food, and thus stimulating the sense of taste and the secretion of the digestive juices.

The excessive use of salt as a condiment is however undesirable, for it imposes upon the kidneys an abnormal amount of work.

According to Voit's researches the lavish use of sodium chloride causes an increase of about 5 per cent of nitrogen in the urine; this effect is however due not to an increased consumption of albumen, but to the fact that the salt, by taking water from the tissues, causes an increased flow of urine and hence a more rapid

removal of the urea formed by the liver. If we extend the research by drinking a larger quantity of water to make up for the greater quantity discharged, we shall find that the sodium chloride not only does not increase the consumption of nitrogen, but may slightly reduce it.

We would finally point out that the continued abuse of sodium chloride, as, for instance, a daily diet consisting mainly of salt meat, by increasing the flow of urine causes an increase in the quantity of lime discharged in the urine, and produces an outbreak of scurvy.¹

With regard to the functional importance of the different components of vegetable and animal ashes, it should be noted that the introduction of a considerable quantity of calcium, magnesium, sodium, and phosphorus is necessary for the formation of the bones and cartilages, and potassium and phosphorus are further necessary for the development of the muscles and probably the protoplasm of all cells.

The long time which the excised heart can be made to survive by perfusion with oxygenated Ringer's solution, as compared with the ordinary physiological solution of sodium chloride, proves the importance of potassium and lime for muscular activity and protoplasmic movements in general. A small quantity of potassium and lime is also indispensable for the development of the fertilised ovum (J. Loeb). A pure solution of sodium chloride is poisonous without the addition of about 2 per cent of lime and potassium.

Phosphorus is found in articles of food in the form of lecithine, phosphoprotein (casein, vitelline), and nucleoproteins which form the chemical basis of the nuclei of cells. It is almost superfluous to remark that these nutritive products are indispensable to the organism at every stage of life, and more especially during the anaplastic period. Numerous researches prove that these organic compounds of phosphorus, which are contained in large quantities in vegetable and animal foods, are of considerably greater nutritive value than the mineral phosphates contained in the bones (Danilewski, Cronheim, Müller). On the other hand, the value of sodium, potassium, calcium, magnesium, and chlorine is the same whether found in the form of organic compounds or simple mineral salts.

During complete or partial abstinence from salts, there is for the first few days a large excretion of salts, but later the quantity expelled becomes steadily smaller, because the salts are firmly combined with the organic molecules of the protoplasm of the tissues. When the normal diet containing a sufficient quantity of salts is resumed, the salts are partly retained in the impoverished

¹ There is evidence that scurvy is due to the absence of an accessory food factor (vitamine). See p. 49.

organism until the normal condition is regained, *i.e.* equilibrium of the intake and output (Luciani and Lo Monaco).

Just as abstinence from iron produces *oligochromaemia*, a decrease in the haemoglobin of the red corpuscles, so abstinence from calcium produces *rickets* and *osteoporosis*. When, for instance, heifers are given food containing only a small quantity of lime, such as turnips, the thickness of the bones decreases, so that they can no longer support the weight of the body, and become bent as in rickets. If, on the other hand, cattle are given plenty of clover and hay which contain a large quantity of calcareous salts, the bones develop well and become firm.¹

XII. Now that we have studied the influence exercised on the exchange of material by the different substances taken in our food, it will be easy to make a comparative examination of their different uses in the organism, which will serve as the basis for a *physiological classification of articles of food*.

Liebig's old division of alimentary substances into *plastic* and *respiratory* is clearly erroneous, since the whole group of *proteins* act at the same time both as *plastic* foods or constructive material for the tissues and the protoplasm of cells in general and as *respiratory* foods, that is, material for combustion. Liebig's theory had, however, the merit of recognising the proteins as the elements which are most necessary and indispensable in nutrition, without which the development and the recuperation of the tissues are alike impossible. Genuine flesh, as found in nature, that is, chemically combined with organic substances containing phosphorus and salts, contains all the qualities and functional capabilities of the foods essential to life, even when it is almost entirely lacking in fat and glycogen. It not only possesses *plastic* and *respiratory* qualities, but is also able to *stimulate metabolism*. We have indeed seen that in order to make up for the daily *deficit* of nitrogen, which exists during a long fast, it is not enough to give daily an equal quantity of nitrogen in the form of proteins, but a considerably larger quantity is required; and during the alimentary regimen the consumption of nitrogen increases—within certain limits—with the quantity of proteins taken. They therefore intensify metabolism, probably by promoting the trophic activity of the nervous system.

In order to explain the gradual decrease in the consumption of nitrogen during fasting, and the increase during a normal regimen with the quantity of protein taken in, Voit suggested that *circulating proteins*, *i.e.* *dead proteins* absorbed by the digestive tube, are more easily burnt than the tissue proteins which form the essential basis of living protoplasm.

This interpretation, however, is not only arbitrary, but also in flat contradiction to the fundamental and traditional theory of

¹ See also question of vitamins, p. 49.

the inner mechanism of vital activities which was formulated by Liebig, experimentally confirmed by the classical researches of Pflüger and Hering, and elaborated by Verworn in his hypothesis of biogen; according to this theory, the most complex molecules constituting the protoplasm of the cells are extremely labile, that is, they are in a constant state of chemical change, undergoing dissimilation and assimilation, being decomposed and oxidised during activity, and reintegrated or built up during rest (Vol. I. Chap. III.). According to this theory, the circulating protein represents the material destined to be partly assimilated and transformed into tissue protein, *i.e.* living protoplasm, partly stored up as reserve protein, partly transformed into glycogen or fat, and partly oxidised and consumed as a combustible material. Dissimilation or catabolism, equally with assimilation or anabolism, does not depend on the easy oxidation of the *dead protein*, as was thought by Voit, but upon the extreme mutability of the *living protoplasm*. In order that it may be elaborated, stored, transformed, or burnt, dead protein must enter the sphere of action of living elements, must, so to speak, pass through the mesh of the tissues. Dead protein, which comes into circulation as the result of protein feeding, will, by stimulating the fundamental trophic activity of the nervous system, accelerate the varied and complex metabolism of the living elements, either for the repair of loss, the increase of reserve protein, the formation of glycogen and fat, or the combustion of the surplus.

It may further be objected that Voit's theory of the combustibility of *circulating protein* presupposes his other and older theory, adopted by Brücke and A. Fick, that only genuine proteins, absorbed and synthetically reconstituted by the intestine and set in circulation, are able to provide for the repair and consumption of the tissues (Vol. II. Chap. V. 6). The latest researches, made after the discovery of *erepsin*, have proved that the proteolytic process in the intestines does not stop short at the formation of albumose and peptone, but goes on to the formation of *amino-acids*. Although the *circulating protein* might be supplied directly by the protein absorbed as such, or indirectly by the protein synthesised from the albumose and peptone, yet observations show that the greater part of the products of the hydrolysis of protein food are absorbed in the form of amino-acids, and are used as such for the repair and functional consumption of the single elements of the tissues.

If from complex and genuine *protein substances*, which form a complete nutriment, capable of supporting life without any additions, we pass on to the consideration of the other nutritive substances, the collagens, saccharides, fats, condiments, mineral substances, we find that none of these foods and not even all of them put together can be substituted for protein foods, no matter

in what quantities they are taken. This is tantamount to saying that they are *incomplete foods*, i.e. they are lacking in one or other of the properties necessary for life which protein substances possess.

They are not histogenic foods, that is, they cannot form or repair the losses sustained by living protoplasm during functional activity. We have seen that *gelatine* and the *collagenous tissues* in general, *carbohydrates* and *fats*, can only partly take the place of proteins as *combustible* material, as a source of heat and work. The saving in the consumption of nitrogen effected by them is only partial.

Gelatine and *collagenous substances* burn rapidly during a normal alimentary regimen, but less so during fasting. They are good foods for producing heat (*thermogenic foods*), but cannot be stored up as *reserve material*.

Saccharides are excellent for the supply of energy (*dynamogenic foods*). During muscular work they may be substituted for the non-nitrogenous group of the protein molecule which is being burnt, and can preserve from consumption the nitrogenous nucleus by reconstituting and reintegrating the muscular protoplasm. This is why work does not cause any notable or proportionate increase in the nitrogenous products found in the urine (Vol. III. Chap. I.). Saccharides can also be partly stored, either in the form of hepatic and muscular glycogen or in that of fat.

Fats are eminently *thermogenic*, because their combustion produces a great deal of heat; in the organism, however, they burn more slowly than collagenous substances and saccharides. They further possess to a high degree the power of acting as *reserve materials*, accumulating in the various organs, and being deposited in large quantities inside the cells of the adipose tissue.

Condiments (substances extracted from meat, alcoholic drinks, spices, and aromatic substances) are necessary ingredients in a good diet, since—by stimulating the senses of taste and smell—they promote the secretion of the digestive juices, and, by raising the tone of the nervous system as a whole, increase the direct or indirect trophic influence exercised by it on the various tissues. Certain condiments are nutritious (cocoa, or thermogenic alcoholic drinks); but all of them act as *nerve stimulants*, and may as such be regarded as *indirect sources of energy*.

Mineral salts, chemically combined with natural protein food-stuffs, serve as simple building or supporting materials in the structure of the tissues in general, and the osseous system in particular.

Water is the *common solvent*, which is indispensable in every diet. It may be that naturally contained in articles of food, or added to it in more or less large quantities in proportion to the daily loss in the urine, the air expired from the lungs, or the perspiration and sweat.

It does not follow from what we have said that the ideal diet should consist exclusively of either protein substances or substances derived from the animal world. On the contrary, a mixed diet, or the addition of vegetable foods which contain a large quantity of carbohydrates, is undoubtedly the one best suited to man, more especially in our temperate climate. We purpose, however, to treat of the physiological theory of human nutrition as fully as it deserves when we have considered the interesting subject of energetic metabolism.

EDITORIAL NOTE

Accessory Food Factors or Vitamines.—In any consideration of the question of nutrition it is necessary to take into account the important recent work which has shown that there are unknown but essential constituents of food called *vitamines*, the absence of which leads to the *deficiency diseases*, such as scurvy and beri-beri. The chemical nature and mode of action of these substances are unknown; two groups have been recognised, the fat-soluble A, and the water-soluble B. The former is contained in butter, cod-liver oil, and animal fats; it is absent from vegetable oils and is not found in many forms of margarine. Fresh animal foods and vegetables are important sources of these vitamins.

Justice to this important subject cannot be done by means of a note; the reader is advised to consult the recent special report (with bibliography) issued by the Medical Research Committee, Special Report Series, No. 38 (Vitamines), H.M. Stationery Office, London, 1919; also the article by F. G. Hopkins, *Brit. Med. Journ.*, 26th April 1919.

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CHAPTER II

THE THERMIC ECONOMY OF THE ORGANISM

SUMMARY.—1. Potential energy of foods from which the amount of heat developed daily by the organism can be calculated. 2. Homoiothermic and poikilothermic animals; the thermic topography of man; daily variations in temperature. 3. Influence on the average temperature of age, sex, race, climate, seasons, food, muscular activity, psychical activity. 4. Regulation of temperature in homoiothermic animals and man; internal conditions and the vasomotor system which determine the equilibrium of temperature in an environment of moderate warmth; the nervous system as the regulator of the production of heat in order to protect the organism from cold; the nervous mechanisms regulating the loss of heat by the evaporation of moisture from the lungs and skin, in order to protect the organism from heat. 5. Experiments and clinical observations showing the thermic effects of injuries to the spinal cord and brain. General theory of the regulation of the exchange of material and energy by the nervous system. Bibliography.

THE exchange of material which we considered in the preceding chapter is always accompanied by an exchange of energy, or, in other words, a transformation of potential into actual energy or the reverse. In the anabolic phases there is usually an accumulation of energy, endothermic processes, in the catabolic phases a development of energy, exothermic processes, the one being to a certain extent the counterpart of the other.

In all tissues or organs there is a continual development of heat through oxidation; the amount of heat developed during these oxidising processes differs considerably according to the nature and state of functional activity of the part. The heat developed by the tissues or organs is imparted to the venous blood flowing from them, which, circulating through the whole organism, tends to diminish local differences of temperature. The amount of heat developed in a given time by the organism in a state of rest is equal to the total of the energy set free, that is, of the potential energy which is transformed into actual energy. During normal nutrition and equilibrium of the intake and output this amount is about equal to the sum of the potential energy introduced into the body with that portion of the food which is to combine with the oxygen of the air absorbed by means of external respiration. When the equilibrium of the

thermic balance is undisturbed, the average temperature of the body remains the same, and is about equal to the difference between the production of heat from the combustion of the food and the loss of heat to the environment.

The energy set free during the process of oxidation takes other forms besides that of heat, more especially that of work. When, however, this work is not transmitted outwards but is expended in the interior of the organism, as for instance in the case of the heart, the whole amount of work is transformed into heat and can be measured as such.

When we know the amount of the exchange of material, we can calculate with considerable accuracy from the heat of combustion of the food the total amount of heat produced, taking into account the heat equivalent of the external work. Conversely, by determining the amount of heat produced, inclusive of external work, we can calculate almost exactly the total exchange of material, without, however, being able to draw any conclusions as to the consumption of individual food substances.

I. In olden days scientists believed in the existence of an innate heat upon which life was dependent; the heart was regarded as the source from which this heat was derived and from which it was diffused throughout the body by means of the waves of the blood in the arteries. Haller (1760) was the first to point out the inadequacy of this theory by the observation that the heart was no hotter than the intestines or other organs. Boerhaave put forth a mechanical theory of thermogenesis; he regarded the heat as a result of the friction of the blood flowing in the blood-vessels, but Haller showed this theory also to be inadequate by reference to cold-blooded animals. After mentioning the hypothesis of electric action and fermentation of the blood, he expressed his personal opinion as follows: "*Hactenus certe maxime videtur, utique a motu sanguinem incalescere, etsi nondum constat, quare magis quam aqua, et quare non super certum gradum incalescere possit.*"

Not until after Lavoisier (1789), with the assistance of his fellow-workers Laplace and Séguin, had developed his theory of respiration, which he regarded as a slow combustion of the carbon and hydrogen in the animal body, can science be said to have been on the right track leading to a true theory of thermogenesis (see Vol. I. Chap. XI. 2). Lavoisier was, however, wrong in supposing that the heat generated during the combustion of organic compounds was equal to that resulting from the combustion of their elements. Favre and Silbermann (1852) were the first to prove by numerous experiments the inaccuracy of this supposition, and thus cleared the way for a further development of our knowledge of the heat of combustion of the organic substances of food and the different constituents of which our organism is composed.

Frankland (1866) was the first to investigate the heat value of certain organic compounds; Stohmann (1877) extended his researches to the most important foods and constituents of the body; and Rubner (1885) and Berthelot (1889) worked along the same lines, carrying out the calorimetric estimations with much more perfect apparatus. Still more recently (1890-91-92) Stohmann, with the help of Langbein, made a careful revision of the results he had already obtained, and added largely thereto.

The Calorimetric Bomb.—This method, which was introduced by Berthelot, enables us to determine exactly the heat of combustion of a large number of organic compounds. The apparatus (Fig. 5)

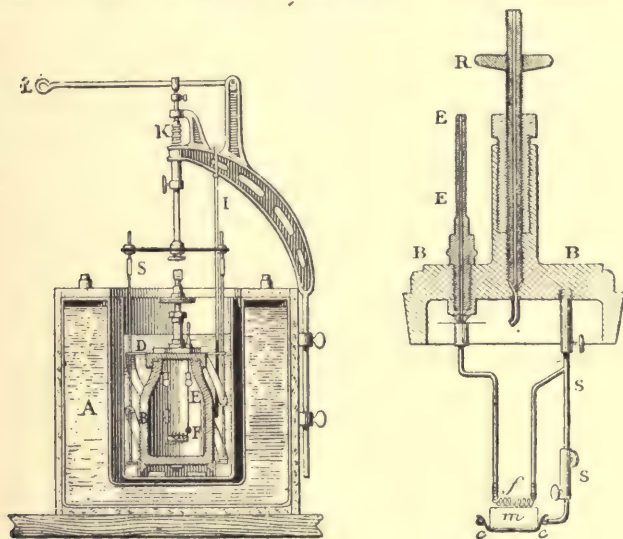


FIG. 5.—Berthelot's calorimetric bomb.

consists of a steel vessel capable of resisting pressures of 200-300 atmospheres, the inner surface being covered with a special enamel which is not affected by either acids or damp oxygen. The cover is furnished with a central tube *R*, which connects the interior of the vessel with a receptacle containing compressed oxygen, and with a lateral tube *E*, which is hermetically closed by a small ivory cylinder, through which passes a platinum wire for conducting the electric current to the spiral wire *f*; when the spiral becomes incandescent, the substance under examination placed in the small capsule *ce* attached to the lower end of the support *S* is burnt.

The calorimetric estimation is made in the following way: a given quantity of the substance is placed in the capsule *ce*, the spiral wire *f* is brought into direct contact with it, the bomb is

hermetically closed, filled with oxygen under a pressure of 25 atmospheres, and then is entirely immersed in the water of the calorimeter *A*. When uniform temperature has been established, the electric current is passed through the spiral wire, which becomes incandescent and sets the substance on fire; the combustion owing to the high pressure of oxygen is instantaneous and complete, the products of oxidation being carbon dioxide and water.

If the capacity for heat of the water in the calorimeter has been previously determined by burning in it a definite quantity of a substance with a known heat value, and also the remaining constants of the apparatus, including the weight and heat produced in the spiral wire, the heat of combustion of the substance under examination can readily be calculated from the data obtained.

The following table shows the results obtained by the three authors already mentioned for the thermogenic value of the most important organic food substances; the figures relate to 1 grm. of the substance, and the heat of combustion is expressed in large calories (1 cal.=the heat required to raise the temperature of 1 litre of water from 0° to 1° C.).

Organic Compounds.	Stohmann.	Berthelot.	Rubner.	Stohmann. Percentage of Nitrogen.
Ethyl alcohol . . . . .	...	7·080	...	...
Glycerine	4·316	...	...	...
Glucose	3·743	3·762	...	...
Galactose	3·737	...	...	...
Cane sugar	3·955	3·962	4·001	...
Dextrine . . . . .	...	4·119	...	...
Starch	4·183	4·228	...	...
Glycogen . . . . .	...	4·190	...	...
Animal fat	9·500	...	9·423	...
Butter	9·231	...	...	...
Vegetable oil . . . . .	...	9·520	...	...
Urea	2·537	2·525	2·523	46·7
Uric acid	2·741	2·747	...	33·3
White of egg	5·735	5·687	...	15·2
Veal	5·721 ¹	5·728	5·778 ²	16·4
Serum albumen	5·918	...	5·754	15·2
Casein	5·858	5·626	...	15·8
Ossein	5·040	5·410	...	16·3
Chondrin	5·131	5·342	...	15·1

¹ Without fat and after removal of the extractives by boiling.

² Extracted with water, alcohol, ether, and free from ash.

In the same way as in the calorimeter, but much more slowly, the food taken into the organism and the organic substances of which the tissues are composed are consumed in the body by the

oxygen absorbed by the lungs. This process transforms potential into actual energy, which in the case of a man doing no external work appears almost entirely as heat.

When the quantity of heat which can be developed by the complete combustion of 1 grm. of each food-stuff is determined in calories and the amount of each substance taken by a man in twenty-four hours is also known, a simple calculation will show how many calories are developed by him daily. When making this calculation we must be careful to distinguish between the consumption of fat and carbohydrates, which are completely consumed in the organism and transformed into water and carbon dioxide, and that of proteins, which undergo a partial process of oxidation and are transformed into urea and other nitrogenous products, representing a considerable amount of potential energy which is not used by the organism. For this reason we must deduct from the heat of combustion of protein the thermic value of the final nitrogenous products contained in the urine and the faeces.

Rubner determined the heat developed in the body by proteins in the following way: He fed a small dog on proteins similar to those which he used for the calorimetric determination of the heat of combustion, and determined the heat of combustion of the corresponding urine; this he found to be 1.0945 cal. per gramme of albumen consumed. In the next place the heat of combustion of the faeces was found by experiment to be 0.1854 cal. per gramme of albumen, and 0.05 cal. was allowed for the heat absorbed by the solution of the albumen and the urea. The physiological value of 1 grm. of dry albumen, including the ashes, would thus be represented by $5.754 \text{ cal.} - (1.0945 + 0.1864 + 0.05) = 4.424 \text{ cal.}$

A similar calculation showed the available physiological value of 1 grm. of muscle free from water and fat but including the ash to be equivalent to 4.001 cal., and in the case of muscle from an animal which had died of inanition 3.842 cal.

We have already seen that in studying exchange of material the amount of protein consumed is calculated from the quantity of nitrogen eliminated. Expressing material exchange in terms of energy, we find that 1 grm. of nitrogen discharged corresponds to 26.66 cal. in the case of albumen, and 25.98 cal. for muscle. The heat of combustion of human urine corresponds on an average for 1 grm. of nitrogen to 8.0 cal.; that of human faeces per gramme of nitrogen varies greatly between 66 and 159 cal.; but the range is much less per gramme of organic substance—from 5.2 to 7.7 cal.; and 6.5 may be taken as an average figure (Rubner, Atwater, Loewy).

When we desire to calculate from the intake and output the calories developed daily by the organism, we must be satisfied

with approximate and average figures, since it is almost impossible to specify the quality and quantity of the different proteins, fats, and carbohydrates of which our articles of food are composed. For the purpose of such estimations Rubner has calculated from the preceding exact determinations the average physiological values for the heat of combustion of the three principal groups of organic food substances; they may be used without any great risk of error in all cases in which we know the total amount of protein, fat, and carbohydrate taken in the food. According to Rubner, 1 grm. of protein yields 4.1 cal., 1 grm. of fat 9.3 cal., and 1 grm. of carbohydrate 4.1 cal. On the principle of the conservation of energy, these theoretical values should correspond to the heat actually developed by the combustion of the said substances within the living organism. The direct proof of the correctness of this deduction Rubner obtained by ascertaining in dogs the total exchange of material, the estimated heat value of the three groups of food substances given to them, and by direct determinations the amount of heat developed during the same period. A comparison of the production of heat calculated from the exchange of material with that found directly with the calorimeter showed in eight series of researches spread over a period of forty-six days a difference of only 0.30 cal. per cent.

Atwater and Benedict repeated such researches on men kept upon a normal mixed diet. They not only analysed the intake and output, but also determined the heat of combustion for both, and at the same time measured the loss of heat by means of a specially constructed calorimetric chamber.

Many forms of physiological calorimeters have been suggested for the measurement of the heat produced by animals and man under normal and pathological conditions. The most important ones will be considered.

The general principle common to all these calorimeters is that the source of heat—the animal—must be so placed that it produces variations of temperature in a suitable medium, the calorimetric medium. The exact measurement of such variations, or a measurable effect of the said variations, affords the data for the calculation of the heat produced by the animal.

The different calorimetric methods are classified according to the nature of the calorimetric medium—*A* solid, *B* liquid, and *C* gaseous calorimetric medium.

A. Of the apparatus of the first type we may mention, because of its historical importance, the one for small animals constructed by Lavoisier and Laplace, in which ice is used as the calorimetric medium. The heat produced by the animal is used to melt the ice, the heat produced being calculated from the resulting water. Fig. 6 shows the calorimeter, which consists of three concentric cavities, of which the innermost, *A*, contains the animal; the middle one, *B*, filled with pieces of ice at 0° is provided at the bottom with a tube having a tap *D*, from which the water resulting from the melting of the ice by the heat produced by the animal runs into the vessel *G*. The third or outer cavity *C* is also filled with ice, and serves to isolate the second from the external temperature. Naturally, only the water which collects in *G*, as the result of the melting of the ice by the heat of the animal, is taken into account.

There are numerous and serious defects in this method, amongst which we may mention the impossibility of measuring accurately the quantity of water produced, since some of it adheres to the pieces of ice and to the sides of the calorimeter, and of renewing the air for breathing, and finally the considerable lowering of temperature to which the animal is subjected. For these reasons physiologists have recourse to other and more satisfactory methods.

B. We may divide the numerous forms of calorimeter with a fluid medium (water) into: (*a*) Methods in which the man or animal is brought into direct contact with the medium, the bath method, which has numerous defects and drawbacks; (*b*) methods in which the man or animal is separated from the calorimetric medium by a space filled with air, methods which have numerous advantages and have been used in two different ways, in one of which the water is gradually heated, while in the other it is kept as far as possible at the same temperature.

The former plan is carried out in Dulong's calorimeter (Fig. 7), which is

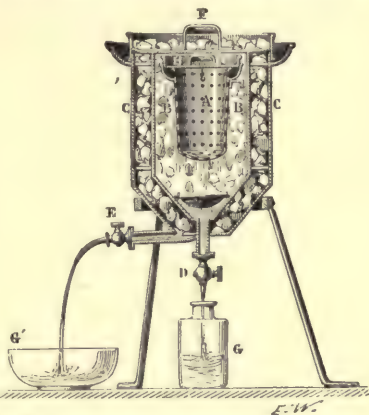


FIG. 6.—Ice calorimeter of Lavoisier and Laplace.

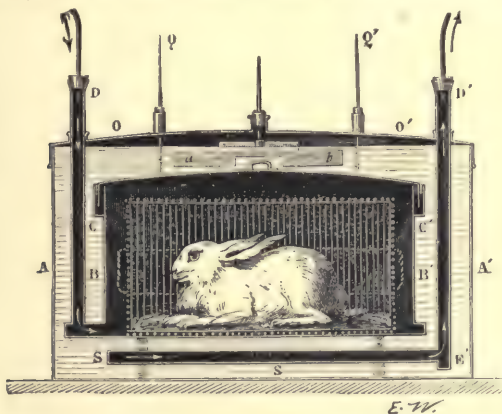


FIG. 7.—Dulong's water calorimeter.

suitable for small animals used for experimental purposes. It consists of two concentric chambers having thin metal sides. The inner of these chambers, *B B'*, for the animal's cage, is closed with an air-tight and water-tight lid,

thus limiting the air space with which the animal comes in contact. The outer chamber, *A A'*, contains a quantity of water, the calorimetric medium, sufficient to cover the chamber *B B'* entirely. In order that the air breathed by the animal may be renewed, the inner chamber communicates with the tube *D*, which supplies it with fresh air from outside, while the vitiated air escapes through the tube *D'* by means of the coil *S* at the bottom of the cage (shown in horizontal section in the figure); one opening *E* is in communication with the inner chamber, while *E'* is a continuation of *D'*. Thus the expired air before coming into the open air has time to acquire the temperature of the water in the calorimeter. In order to distribute uniformly the heat acquired by the water, the wing-shaped fan *a b* is set in motion. The rise in

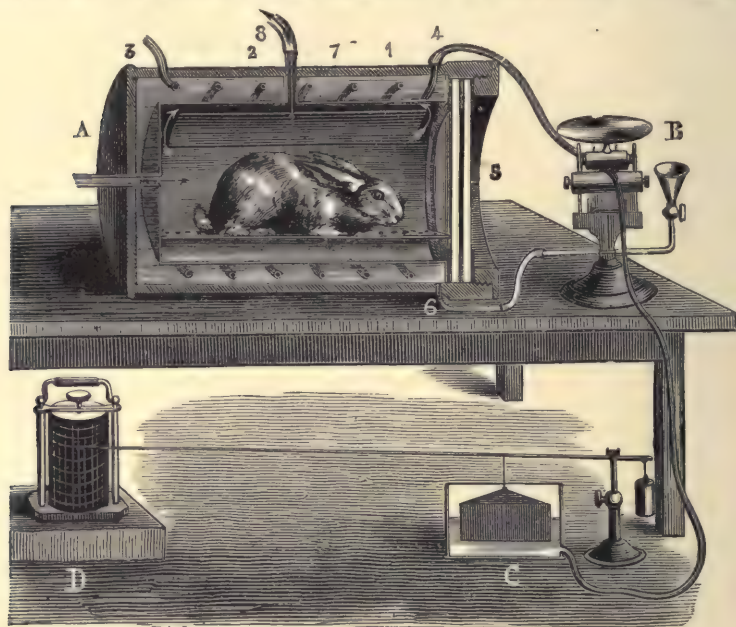


FIG. 8.—D'Arsonval's compensation calorimeter.

the temperature of the water due to the heat produced by the animal is indicated by the two thermometers *Q* and *Q'*.

This calorimeter is open to various objections, of which the most serious is that inherent in the method, *i.e.* the raising of the temperature of the environment of the animal, which, as we now know, has a great effect upon the regulation of temperature in the animal and the radiation of heat. For this reason calorimeters in which the liquid is kept at the same temperature are preferable. Of these methods the best is that of d'Arsonval, called the *compensation calorimeter*.

As will be seen by Fig. 8, it consists of two concentric cylinders of metal confining two cavities, of which the inner one holds the animal to be experimented on, and the outer one the calorimetric liquid (water, petroleum, etc.). Through the liquid passes a coiled cooling tube, one end of which is connected with a supply of cold water at 0° , whilst the other end communicates by means of an indiarubber tube 4 with the receptacle *C*, arranged to receive the water which escapes.

The indiarubber tube, before reaching the receptacle, passes through the regulator of the outflow *B*, which adjusts the escape of the liquid automatically, so that the cold water only escapes when the temperature of the calorimeter is higher than that of the outer air. The automatic working of this regulator will be readily understood from the illustration. By means of tube 6 it is directly connected with the liquid in the calorimeter. If weights be placed on the pan in such a way as to compress the indiarubber tube 4, the liquid cannot escape through the tube. As soon, however, as the animal is placed in the calorimeter, the liquid becomes hotter and therefore expands; this expansion, transmitted through tube 6 to the lower cylinder of the regulator, raises the weight pan and thus allows a compensating escape of cold water. It will be seen that in this way the temperature of the calorimeter is kept uniform.

The recipient *C*, in addition to receiving and measuring the quantity of water which escapes, affords also a graphic record, as will be seen from the figure.

The ventilation of the environment of the animal is secured by a current of air which enters by tube *A* and makes its exit by tube *S*.

In order to obtain reliable results the apparatus must of course be kept from variations in the temperature of the outside air; this condition can be obtained by covering the calorimeter with an outer isolating jacket, or experimenting in a laboratory in which the temperature is kept constant.

On the principle of this calorimeter with a uniform temperature Atwater constructed the large calorimeter used in his well-known researches upon the exchange of material and energy in man. It is a real room, in which the person can spend days and nights, and which allows of the exercise of all his functions. The inner free space measures 2.15 metres in length, 1.92 in height, and 1.22 in width. It is shut off from the outside by a double wall of metal, the inner one being copper, the outer zinc. Between the two walls there is an air space about 7.6 cms. wide. To prevent the calorimeter being affected by variations in the temperature of the outside air, it is encased in two or three wooden covers, about 5 cms. apart.

There is, for the purpose of keeping its temperature uniform, outside the zinc wall and inside the first wooden one, a system of silver-plated wires and iron tubes, the former for the purpose of heating the calorimeter by sending an electric current through it, the latter for the purpose of cooling it by the passage of a current of cold water. Provision having thus been made against the loss or gain of heat through the walls of the calorimeter, it remains to conduct away and measure the heat produced inside it by the subject of the experiment. In order to do this, the temperature of the water in entering and leaving the system of tubes in the calorimeter is recorded with an extremely sensitive thermometer divided to $\frac{1}{100}$ of a degree. In addition, the quantity of water circulating through the system is measured with an accurate meter.

The room occupied by the subject of the experiment is ventilated by means of a special apparatus. Both the ingoing and the outgoing air are brought into equilibrium with the temperature of the calorimeter by means of special contrivances. In order to make his researches still more perfect, Atwater analysed the respiratory gases, and also the intake and output of material, *i.e.* he studied not only the dynamic but also the material exchange, which makes the prosecution of the plan of research far more complicated. This will be realised from the fact that in each of his experiments the services of at least twelve persons were required.

C. There are two kinds of calorimeter having a gaseous medium (air): (*a*) those in which the air serving as the calorimetric medium comes into direct contact with the animal; (*b*) those in which the calorimetric air is not in direct contact with the source of heat, but is contained in an

annular cavity of a receptacle having double walls, the animal to be experimented on being placed in the inner cavity.

Of the first class we may mention d'Arsonval's anemocalorimeter, which, though not very accurate, is in its simplicity admirably adapted to physiological or clinical experiments on man.

The principle on which this method is based is that hot air tends to ascend, producing a current of air from below upwards the velocity of which is in proportion to the quantity of heat produced.

As will be seen by Fig 9, A, the apparatus consists of a tent of silk or woollen material about two metres high, not touching the ground, but held up by a three-legged support; within it a man can stand upright. In the roof is a conical funnel, of which the outlet is bent at a right angle and the inlet is large enough to contain the anemometer shown in Fig. 9, B. This anemometer is a very light windmill; the eight aluminium sails placed at an angle of 45° to the axis of rotation are set in motion by the current of air,

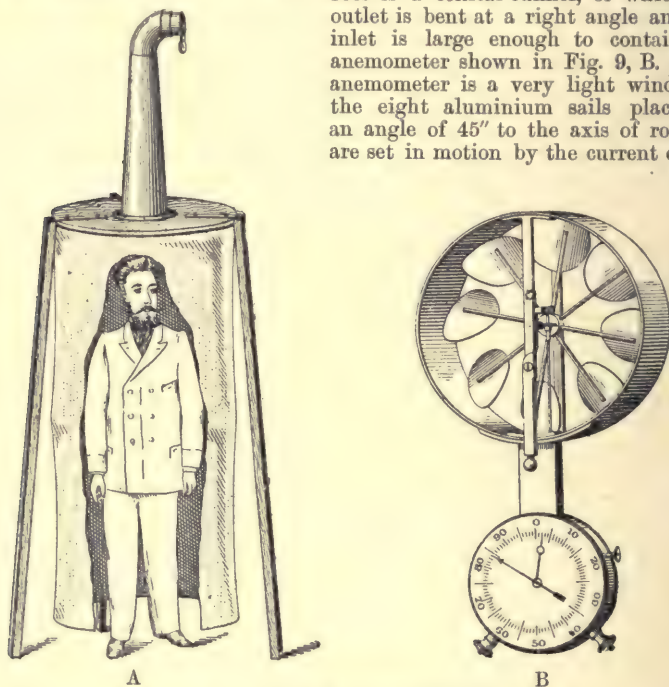


FIG. 9.—D'Arsonval's anemocalorimeter.

which, ascending from inside the tent, passes through the funnel. The movement of the wings is transmitted and measured by the meter attached below.

In order to carry out researches with this apparatus, it must first of all be tested and graduated. This is easily done by placing in it a constant source of heat and noting the number of revolutions registered by the meter in a given time—five minutes for instance—when the mill has reached its maximum velocity. In experiments on man, a certain time—ten minutes will usually be long enough—must be allowed to elapse between the placing of the person in the apparatus and the starting of the meter in order that the windmill may attain its maximum velocity and uniform motion.

D'Arsonval was able without difficulty to convert this calorimeter into a calorigraph, by placing the meter in an electric circuit which was closed when

the needle of the meter passed the zero. The electric current then acted on an electric magnet which set a pen in motion.

The principle underlying calorimeters of the second type consists in the method of measuring the temperature, which is not done with the thermometer, but by making use of the expansion of gases; the variations in volume under constant pressure are directly proportional to the alterations in temperature. Of apparatus of this type we may mention the air calorimeters used by d'Arsonval for man and animals.

The former, as will be seen by Fig. 10, is made of two metal cylinders, one over the other, containing two cavities: an inner one in which the subject of the experiment is placed, and in which there circulates a current of air in the direction indicated by the arrow; and an outer one, hermetically closed, containing the quantity of air which serves as the calorimetric medium.

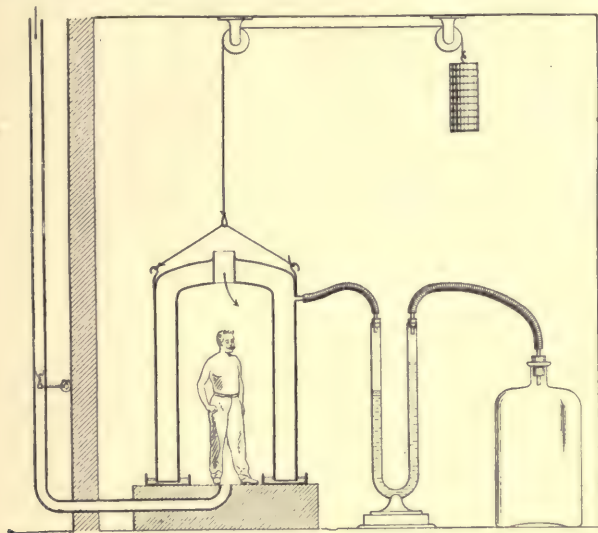


FIG. 10.—D'Arsonval's air calorimeter.

The variations in the volume of this air, due to the alterations in temperature set up by the source of heat, are registered by the U-shaped water manometer, of which one limb is in direct communication with the air in the calorimeter and the other with air contained in a large vessel placed in the same room as the calorimeter for the purpose of neutralising the effects of the variations of temperature which are not due to the subject of the experiment.

The same purpose is served by the arrangement of the calorimeter for animals shown in Fig. 11, in which one limb of the recording manometer is connected with the circular space between the two metal sides of the calorimeter in which the animal is placed, while the other limb communicates with the space of another calorimeter of the same size, but empty.

It is clear that this arrangement gives a real differential thermometer, which constantly indicates how much higher the internal temperature is than that of the external surroundings.

Both calorimeters are in direct communication with the air contained in two extremely light metal cylinders, which dip into the water filling the larger outer cylinders. The movable cylinders are connected with the two arms

of a balance, which carries a pen at one end. It is obvious that if the two systems be heated to the same degree, the two cylinders will not be displaced and the balance will remain in equilibrium. If, however, one of the calorimeters be heated while the temperature of the other remains unaltered, the expansion of the air in the first will raise the corresponding cylinder, and the pen will trace an ascending line on the kymograph. The arrangement of

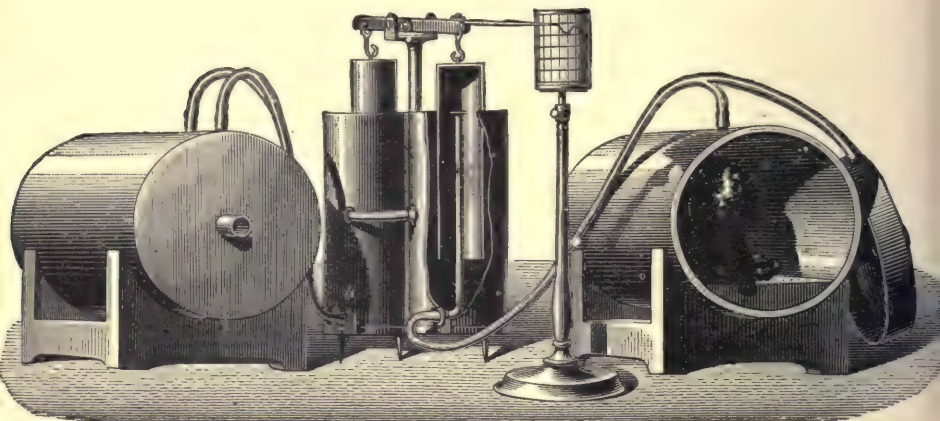


FIG. 11.—D'Arsonval's differential calorimeter for animals.

this differential calorimeter has also the advantage of allowing comparative experiments to be carried out on two animals at the same time.

The following table shows the numerous data obtained by Atwater in a series of experiments on man. In it the calories estimated (A) are compared with those found with the calorimeter (B), and the percentage difference (B-A) is given. All the results refer to the same person, and the figures express in large calories the heat produced for an average of twenty-four hours on a normal mixed diet during rest and muscular work.

[TABLE

A. Calories calculated from heat of combustion—in- take and output.	B. Calories directly ascer- tained by means of the calorimeter.	Mean values of A and B.	Difference per cent between A and B.
At rest.	2482	2379	- 4·1
	2432	2394	- 1·6
	2361	2287	- 3·2
	2277	2309	+ 1·4
	2268	2283	+ 0·7
	2112	2151	+ 1·8
	2131	2193	+ 2·9
	2216	2176	- 1·8
	2238	2272	+ 1·5
	2304	2279	- 1·1
	2242	2244	+ 0·1
	2043	2085	- 2·0
	2067	2079	- 0·6
Average	2244	2241	- 0·1
At work.	3839	3726	- 2·7
	3901	3932	+ 0·8
	3515	3589	+ 2·1
	3439	3420	- 0·6
	3573	3565	- 0·2
	3629	3587	- 1·2
Average	3647	3637	- 0·3
Total av.	2688	2682	+ 0·2

This table shows that the maximum difference between A and B, that is between the calories estimated and found, amounts to 4·1 cal. per cent, while the minimum difference is 0·1 cal. per cent. The average difference between A and B in all the investigations made during rest is 0·1 cal. per cent; in all those made during muscular work 0·3 cal. per cent; the total average, that under the usual circumstances, when work alternates with rest, is 0·2 cal. per cent. These experimental results justify the conclusion that nutritive substances in the course of their combustion within the organism develop the same amount of heat as when burnt outside, a conclusion in harmony with the law of the conservation of energy. They also prove that the quantity of heat developed daily by the organism can be calculated with sufficient accuracy from the data of the exchange of material, on the basis of the *average values* (standard figures) given by Rubner and Atwater and Benedict for the heat of combustion of the three main groups of organic food substances.

II. As regards the production of heat, vertebrates are divided into two classes, those with an invariable and those with a variable temperature. The former class, represented by mammals and birds, were designated *homoiothermic animals* by Bergmann; the

latter, represented by reptiles, amphibia, and fish, he called *heterothermic* or *poikilothermic animals*.

The former class maintain their average temperature within certain narrow limits of variation, even when exposed to great changes in the temperature of their environment. In order to account for this relatively uniform temperature, we must remember that when these animals are kept for a long time in cold surroundings their production of heat is increased in order to compensate for the loss of heat; on the other hand, their production of heat diminishes when they are kept in warm surroundings. Their life is endangered when, owing to exposure to extreme cooling or heating, a big fall or rise is produced in their temperature.

Poikilothermic animals, on the contrary, can endure without any danger to life great changes in their temperature, produced by variations in the temperature of the environment in which they live or in which they are placed for the purpose of experiment. They too, however, have a *temperature of their own* somewhat higher than that of the environment; they too, like homiothermic animals, are capable in some small measure of reacting to the external temperature by increasing or decreasing the processes of oxidation, and hence the production of heat.

There is a class of animals occupying a position midway between the homiothermic and the poikilothermic animals. The so-called *hibernating* animals and *new-born* animals in general form an exception in the group of mammals and birds. These animals cannot maintain their temperature within normal limits when that of the environment is considerably lowered. When their temperature falls below 20° they fall into a state of lethargy (Ch. Richet).

Variations in temperature are usually measured with thermometers. There are various kinds of thermometers, but they are all based on the same principle, *i.e.* that a determined quantity of the thermometric substance varies in volume according to the temperature. Every increase in temperature causes an expansion or increase in volume.

The only condition which is essential if a substance is to be regarded as thermometric is that its volume shall not be the same in two different states of heat. This is why water cannot be used. It therefore follows that the greater the volumetric variations produced in the thermometer by heat, the better will it answer its purpose. In other words, gases would be the best substances for thermometry. Their use, however, has many practical drawbacks, and for this reason the hydrogen thermometer is only used in physics as a standard instrument.

The thermometer most commonly used is one in which mercury serves as the thermometric substance. For the measurement of very slight variations of temperature there are thermometers (Baudin) which allow direct reading to $\frac{1}{50}$ of a degree and estimation to $\frac{1}{100}$. The attainment of such perfection of course necessitates the use of a very large quantity of mercury—the bulb is therefore large—and of a very slender tube in which the column of mercury rises and falls.

The thermometric scale most used is that known as the *Centigrade* or *Celsius* scale, in which the two fixed points are: (a) the point corresponding to the temperature at which ice melts; (b) the point at which water boils at a barometric pressure of 760 mm. of Hg. The former is the zero, the latter the 100th division of the thermometric scale; the interval between the two is subdivided into 100 equal parts indicating the degrees of temperature.

The same two points are used in Réaumur's scale, with this difference, that the higher division corresponds to 80 and not to 100, and therefore the whole scale is divided into 80 degrees. In order to express the degrees of Réaumur's thermometer in Centigrade degrees, it is only necessary to multiply the Réaumur degrees by 1.25 ($\frac{5}{4}$).

The two fixed points of the scale of Fahrenheit's thermometer, which is used in England, are the temperature of a freezing mixture of salt and crushed ice, which corresponds to zero, and that of boiling water, which corresponds to 212 degrees. Such a thermometer placed in melting ice registers 32°; hence the interval between the zero and the 100° of the Celsius thermometer corresponds to 180° Fahrenheit; in other words, 1 Fahrenheit degree is equivalent to $\frac{5}{9}$ of a Celsius degree. In order to express the results obtained by a Fahrenheit thermometer in Centigrade degrees, it is necessary to subtract 32 from the Fahrenheit degrees and multiply by $\frac{5}{9}$.

For the measurement of still finer variations of temperature the thermoelectric needles mentioned in Vol. III. Chap. I. are used.

Another electric method of measuring very small differences of temperature is that known as the *bolometrical* method, which has been used successfully in researches upon exchange of energy. This method is based on the principle that the resistance of a metallic circuit to the passage of an electric current varies not only according to the nature and dimensions of the metal, but also to its temperature; the resistance increases in proportion to the warming of the circuit.

The instrument to which Callender gave the name *electric resistance thermometer* consists of a thread of the purest platinum, 5 cms. long and 25 μ thick, having a resistance of 8 ohm at 0° C. This thread is wound on a very thin plate measuring about 3 square mms., and isolated electrically by being coated with wax; its ends are soldered with thin copper electrodes. The total weight of the apparatus is about 4 mgrms.

The apparatus is interposed in one arm of a Wheatstone bridge, of which the other arm is joined to a second identical bolometer, the whole forming part of an electric circuit, in which a galvanometer is placed. Only the first bolometer is put in connection with the source of heat; the second acts as a compensator to eliminate the influence of the variations in the temperature of the surroundings. Such a contrivance allows of the registration of variations of $\frac{1}{10000}$, and even of $\frac{1}{100000}$ of a degree.

We will now consider the temperature of man, which is the one of greatest interest to us. It is perhaps more variable than that of the higher animals, changing, as it does, considerably, according to the hour at which the observations are made. Jurgensen (1873) found in a large number of observations that the average temperature of the rectum in man was 37.34° by day and 36.91° by night. The maximum and minimum temperatures in a normal condition during rest were 37.7° and 36.2° respectively. The corresponding figures found by Jäger (1881) as the result of observations on eleven normal individuals were somewhat lower (37.17° and 36.13°), as were also those obtained by Richet and

Gley for the temperature of the stream of urine (37.35° and 36.4°). The average temperature of the urine in 241 determinations made by Mantegazza was 37.2° .

In the blood-vessels there is a continual movement of the blood, which takes about twenty-four seconds to perform its circuit, and this has a great influence in equalising the temperature of the different parts of the body, but does not bring about perfect uniformity. In general, the exposed surface of the skin and the peripheral parts show a lower temperature than the internal parts of the body, owing to the continual radiation of heat to the environment, and the evaporation of water from the skin and lungs.

If we take at the same time the temperature of the arm-pit, the mouth under the tongue, the rectum or the vagina, we find that the mouth is a little hotter than the arm-pit, while the rectal temperature is always distinctly higher than that of the arm-pit. The temperature of the mouth is 0.1° - 0.2° , and that of the rectum 0.4° - 0.5° higher than that of the arm-pit (Bernard, Gassot, Forel, Crombie, and others).

The temperature of the urine during its flow is in many cases the same as that of the rectum, in others somewhat lower, sometimes even a little higher. According to Pembrey (1898), the average temperature of the rectum is 0.34° higher than that of the urine, owing to the evaporation to which the latter is subject during its flow.

The temperature of the exposed surfaces of the skin varies considerably according to the temperature of the surroundings. According to Rubner (1895), at 10° it is 29° ; at 15° , 29.2° ; at 17.5° , 30° ; and at 25.6° , 31.7° . At the same time he found the temperature of the covered skin to be 32° - 33° .

Not only the temperature of the outer surface, but also that of the deeper parts, varies considerably in the different organs, according to the greater or smaller intensity of their metabolism, the more or less copious supply of blood, and the greater or less protection afforded by their position.

The upper parts of the abdominal cavity are undoubtedly warmer than the rectum. According to Quinke (1889), the interior of the human stomach is 0.12° hotter than the rectum.

Léfevre (1898), in simultaneous determinations of the temperature of the rectum and liver of the dog, found that the latter was 1.1° warmer than the former (39.6° - 38.5°); Cavazzani (1894) found the liver of the dog to be 0.14° - 0.63° hotter than the arterial blood, and in normal conditions always warmer than the rectum.

According to the researches made by Liebig (1853), C. Bernard (1876), Heidenhain and Körner (1871), the venous blood in the internal organs is higher than the arterial, whereas in the parts near the surface it is somewhat lower. The blood in the

hepatic vein is the warmest (39.7°); next comes that of the right side of the heart (38.8°), and then that of the left side of the heart. These differences are not due only to the heating of the air inspired and the evaporation of water in the lungs, since—according to Heidenhain and Körner—results differing but slightly are obtained when artificial respiration is practised with air saturated with moisture and heated to 35° – 40° . They came to the conclusion that the higher temperature of the right side of the heart, compared to that of the left, is mainly due to the heat transmitted to the right heart by the venous blood coming from the liver.

In addition to the local differences of temperature it is interesting to study more closely the normal variations of the temperature of man in the course of twenty-four hours; for differences are found even when the temperature of the same part of the body (the rectum or the arm-pit) is taken. These variations take a regular course which has been the subject of many researches, the temperature being methodically tested at every hour of the day and night.

As early as 1843 Chossat, when studying the phenomena of inanition in pigeons, noticed that on a regular diet the difference in the temperature of these birds during the day and the night averaged 0.74° (42.22° at noon, 41.48° at midnight), and that this difference steadily increased during inanition, becoming 2.3° in the first stage, 3.2° in the second, and 4.1° in the third, the one immediately preceding death. He saw that this steady increase of the difference between day and night temperatures during inanition was due to an abnormal lowering of the night temperature, the temperature of the body remaining almost unchanged during the day.

In 1845 the daily variations of temperature were tested by J. Davy, and later by a large number of investigators, among them being Jürgensen (1873), Liebermeister (1875), Ringer and Stuart (1877), Richet (1889), Benedict and Snell (1902-1904). The results obtained agree in the main and only differ in details of secondary importance, which may be accounted for by differences peculiar to the different subjects and the conditions under which the observations were made. The normal curve of the variations in temperature in the course of twenty-four hours given by Jürgensen shows a very regular course, as will be seen in Fig. 12, A, reaching its minimum between 4 and 6 in the morning and its maximum between 4 and 6 in the afternoon. During the day the subject remained at rest in bed and took his usual food. The curve Fig. 12, B, was obtained in the same person when fasting; it differs but little from curve A. The range is 0.8° in the case of A, and 0.6° in B. When the subjects do not remain in bed during the day, and do not perform any real muscular work, the difference between the minimum temperature of the night and the maximum

temperature of the day is considerably greater, and may be as much as 1° - 1.5° .

More accurate are the curves obtained by Benedict and Snell for a student 20 years old, who, during the whole period of observation, was shut up in Atwater's calorimetric chamber, in

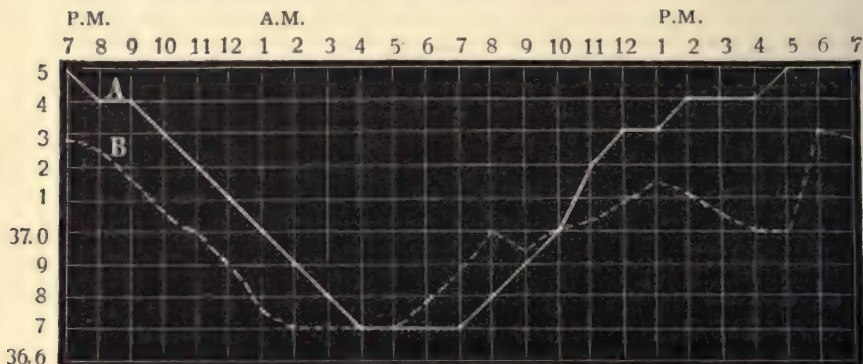


FIG. 12.—Variations in temperature during two days spent at rest in bed (Jürgensen): A, on the ordinary diet; B, when fasting.

a uniform temperature of 19° . The determinations of the bodily temperature were carried out by the bolometrical method, and on an average every twelve minutes. Fig. 13 shows the curve of the daily variations of temperature during rest and on a diet, Fig. 14, those during fasting, all other conditions remaining unaltered. A



FIG. 13.—Daily variations in the temperature of the body during rest and on the usual diet, obtained by the bolometrical method. (Benedict and Snell.)

comparison of the two curves shows that the general course of the variations is the same; but the range in the former curve is 0.93° , in the latter 1.18° .

These variations prove that the thermic regulation of man, and of homoiothermic animals in general, is not as perfect as that of a thermostat. On what do the hypothermia of the night and the hyperthermia of the day depend?

Since the normal variations in temperature persist even during fasting, and when the temperature of the environment is kept uniform, we must conclude that they are independent of nourishment and changes of external temperature.

At first sight it seems reasonable to ascribe the hyperthermia of the day to muscular activity, which is undoubtedly always greater by day than by night. If, however, the course of the curve be considered, we shall find this theory to be inadequate, since the hours during which the temperature rises do not coincide with increased muscular work, and those during which it falls do not correspond with a gradual decrease in muscular activity. Moreover, Jürgensen's curve was obtained in an individual who remained in bed the whole twenty-four hours; the

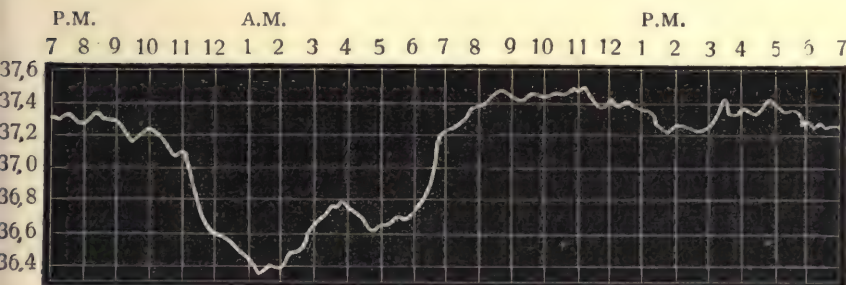


FIG. 14.—Daily variations in the temperature of the body when fasting and at rest, obtained by the bolometrical method. (Benedict and Snell.)

curve of the variations, therefore, does not appear to be explained as the result of muscular activity and rest.

In default of other explanation, the daily variations in temperature may be regarded as due to an *automatic variation in the regulation* of temperature by the nervous system. In the morning the temperature of the body is regulated for 36.5° , in the evening for 37.5° .

"Il me paraît évident (writes C. Richet) que le système nerveux traverse dans le cours d'une période de vingt-quatre heures des phases d'excitation et de dépression, qui se traduisent par un niveau variable de régulation thermique."¹ Just as in psychic life there is a period of wakefulness and a period of sleep, so in organic life there is normally a period of hyperthermia and one of hypothermia, independent of the hours of meals, the external temperature, the latitude, etc., and dependent upon the positive and negative variations in the *functional tone* of the nervous

¹ "It appears to me evident that the nervous system passes in the course of a period of twenty-four hours through phases of excitation and depression which are shown in a variation in the levels at which the temperature is regulated."

system, which regulates both the production and the loss of heat.

Sondén and Tigerstedt (1895) determined from hour to hour the quantity of carbon dioxide discharged, and found that the curve of the daily variation in temperature corresponded very closely with that of the discharge of carbon dioxide. They came to the conclusion that the variation in temperature coincides with a variation in the intensity of the exchange of material.

Without detracting from the value of this conclusion, it does not seem to me to contradict the theory that the nervous system, by controlling the chemical phenomena of the organism, acts as the *regulator of thermogenesis*. It merely leads us to the conclusion that the hypothermia of the night and the hyperthermia of the day are due respectively to diminished and increased *production of heat*, and not to increased and diminished loss.

Tigerstedt, however, considers the most important cause of the daily variations in temperature to be the muscular movements which take place while the body is in a state of rest in bed. His pupil, Johanssohn (1897), noticed that when sitting still or lying in bed in a fasting condition we intentionally avoid making any movement, the discharge of carbon dioxide during the different hours of the day varies very little as compared with the variations noticed in ordinary conditions of nourishment and relative rest. Even in these conditions, however, there is the characteristic daily variation in temperature; the minimum is noticed at 4 A.M., and the maximum at 7 P.M., although the difference between the two only amounts to 0.5° , as against 1.1° under ordinary conditions. This proves to my mind that while muscular activity is an important factor in regard to the combustion and temperature of the body, it does not afford an adequate explanation of the daily variations of temperature. Everything tends to prove that this variation is an outward expression of an alternation of activity and rest in the nervous system, a view which would agree with the old theory advanced by Chossat, who considered the nightly fall in temperature to be due to rest and sleep, to the cessation of all the stimuli which act on the nervous system during the hours of wakefulness, and tend to increase the metabolism and the temperature. He found, indeed, that if animals are awakened during the night, their temperature rises, and soon reaches the point which he observed normally in the morning.

Is it possible to invert the daily variation in temperature by inverting the usual mode of life, that is, by sleeping during the day and remaining awake, eating, and working during the night? Krieger (1869) appears to have been the first to try this experiment. He states that he succeeded in obtaining a complete inversion of the daily curve of temperature; he did not, however, give the exact data of his observations. Debzynski (1875), by

inverting the mode of life, obtained the maximum temperature in the morning (37.8°) and the minimum in the evening (35.3°). Carter (1890) mentions that in an engineer who was in the habit of sleeping during the day and working at night, the temperature was 37.25° in the morning and 36.8° at night. Finally, Jager (1881) records observations on four army bakers who worked at night, and in whom he found at all events a partial inversion of the normal curve of temperature, which disappeared when one of the bakers remained a whole day in bed.

Other observers, however, did not succeed in getting a real inversion of the daily curve of temperature, but merely a modification of it. Thus U. Mosso (1887), after a four days'

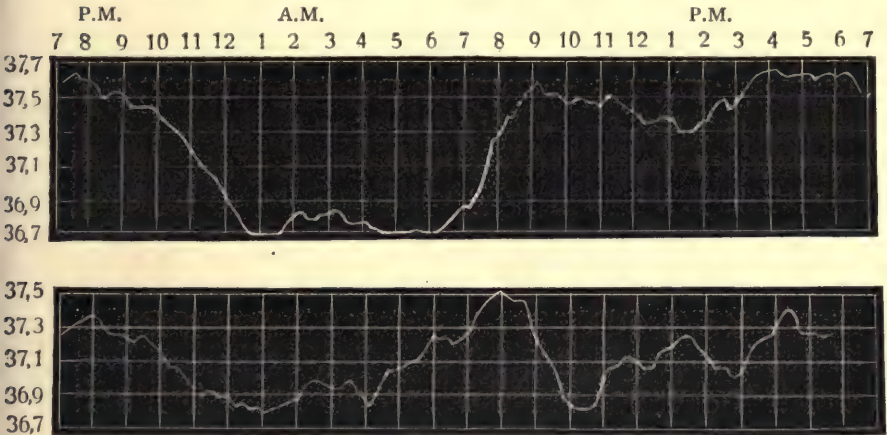


FIG. 15.—Daily variations in the temperature of the body (Benedict and Snell).

The upper curve is the usual curve of rest, when nourishment is given at the ordinary hours; the lower curve was obtained on the tenth day after inverting the hours of meals and sleep.

inversion of the normal mode of life, found a partial displacement of the hours of maximum and minimum temperature. He also found that the average temperature increased from 36.7° to 37.0° ; he could not, however, obtain a complete inversion of the curve. During sleep, from 11 A.M. to 6 P.M., he observed on the fourth day a relative lowering of the temperature, but not the maximum fall; during waking hours he obtained a double rise of temperature, one from 8 to 9 A.M., the other between 7 and 9 P.M.

By means of the method already mentioned, Benedict and Snell repeated the experiments of inversion of the mode of life on a young man for a period of ten successive days and failed to invert the daily curve of temperature, as will be seen clearly by comparing the normal curve with that obtained on the tenth day of inversion of the mode of life (Fig. 15).

This resistance of the nervous system which controls the

exchange of material and energy to the inversion of the two phases, positive and negative, of its functional tone is undoubtedly the result of habit. Toulouse and Piéron observed a complete inversion of the curve of temperature in the case of nurses obliged for a long period to watch by night and sleep by day. This inversion of temperature, however, was only obtained after several weeks, when the nurses had become thoroughly accustomed to their new mode of life.

Galbraith and Simpson (1903) obtained the same result in monkeys after keeping them for some time in pitch darkness during the day and in the light during the night. When these animals were kept for the whole time during which they were under observation either continuously in the dark or in the light, the characteristic daily curve disappeared and there were only irregular variations in the temperature. Worthy of note is the observation of these investigators, that in night birds the daily curve is the reverse of the normal one characteristic of day birds, which seems a direct confirmation of the older teaching of Chossat.

III. The average temperature varies but little with age. The temperature of the foetus is somewhat higher than that of the mother (H. Roger). The temperature of the rectum of the infant immediately after birth is, according to repeated observations made by Bärensprung, 37.81° , while the normal temperature of the uterus is 37.5° . According to Roger the temperature of the arm-pit of the new-born child is 37.75° , that of the mother being 36.75° . Half an hour after birth it is 37.6° ; ten hours after 37.05° (Andral).

The relative hyperthermia of the foetus and the new-born child is due to the combustion in the foetal organism itself; the gradual hypothermia constantly noticed after birth is probably due to the imperfect development of its nervous system, the regulator of the temperature, and in this respect the new-born child resembles hibernating animals.

A few days after birth the temperature of the child becomes much the same as that of the adult. The temperature of old people does not differ much from that of adults. Charcot found the temperature of the rectum in the old to be 37.2° - 37.5° , and that of a healthy centenarian to be 37.1° in the arm-pit and 38° in the rectum. Mossé and Ducamp, in 180 cases observed, found an average difference in the temperature of the arm-pit and rectum in old people of 75-80 years of age to be 0.45° . In the morning the temperature of the arm-pit was 36.32° , in the evening 36.46° , about a tenth of a degree lower than in middle-aged persons.

Sex exercises no sensible influence on the average temperature. Roger in ten boys found the average temperature to be 37.107°

and in fourteen girls 37.191° . Wunderlich found that there was a rise of temperature of about 0.3° during menstruation; Riehl noticed that this hyperthermia is specially marked during the pre-menstrual period.

Neither does *Race* cause any great difference in the average temperature. Davy, however, considers that the temperature of negroes, Indians, and Malays is some tenths of a degree higher than that of Europeans. This difference appears, however, to be the result of tropical climates rather than of race. Chrisholm and Chalmers, indeed, assert that in hot countries the temperature of Indians and English was the same. Furnell, a doctor attached to the Madras hospital, confirmed this statement, while Livingstone had noticed the same fact in the negroes of Africa.

The more recent work of Glogner (1891) and of Eijkman (1893) also go to show that no influence is exercised on temperature by race, and that of *tropical climates* is but slight.

Forel took the temperature of his rectum at different seasons of the year, and found that a rise in the temperature of the air caused a slight rise in that of the rectum; while Davy observed that very intense cold caused the temperature of the arm-pit to fall to 35.9° . The same fact was noticed by Stapff.

That great rises or falls in the external temperature can modify the temperature of the body is shown by the fact that death occurs from heat or cold. But what we have already said proves that moderate differences in external temperature, although they may cause variations of a few tenths of a degree in the temperature of the body, are compatible with perfect health. In other words, the temperature may be regulated at a somewhat higher or lower level than the normal one, and the organism still remain within physiological limits.

The influence of *Nourishment* upon the temperature is extremely slight. We have indeed seen that the daily curve is not in the least affected by the hours of meals and that its characteristic course remains unaltered during fasting. This proves the course of the average temperature of the body to be independent of the oscillations in the production of heat. When combustion is more active after a meal (L. Fredericq and others), and does not cause any sensible rise of temperature, it follows that the loss of heat is proportionately increased, and compensates for the increased production.

We know that *muscular activity* exerts a preponderating influence on the production of heat (Vol. III. Chap. I. 10). Muscles form 40 per cent of the total weight of vertebrate animals, and their active exercise is the best means of warming the body in winter.

Davy noticed that his temperature rose from 36.6° to 37.25° after various forms of muscular exercise, and fell to 36.1° after a

drive, though the air was not very cold. According to Jürgensen, muscular work causes a rise in the temperature of about 1.2° , at which point it remains as long as the muscular activity continues. He found a runner's temperature to be 39.5° . Half an hour's quick walk caused the temperature to rise 0.5° above normal.

Even when the temperature of the air is very low, muscular exercise will cause a considerable rise in the temperature of the body. But according to Vernet's numerous observations, the hyperthermia disappears after about twenty minutes' rest, and the temperature becomes normal again.

Even a slight muscular exertion which only lasts a few moments is enough to produce a perceptible thermic effect. Even going upstairs without hurrying particularly will raise the temperature by several hundredths of a degree; it falls to normal after a few minutes' rest.

These phenomena prove that the mechanism regulating the temperature is not sufficiently perfect to re-establish the normal equilibrium between the production and the loss of heat whilst muscular activity is going on. We must admit, as Richet correctly remarks, that it is *always behindhand*, and that some moments of rest are therefore necessary in order to restore the normal temperature.

Psychical activity also raises the temperature about 0.1° above the normal. J. Davy noticed this rise after two to five hours of concentrated attention. Speck, Rumpf, and Gley confirmed the thermic influence of intellectual work lasting some time.

With regard to the cause of this slight hyperthermia, it is difficult to believe that it is directly due to an increase in the process of oxidation; it is more probable, as Richet suggests, that it depends on stimulation of the nerve-centres, resulting in the regulation of the temperature at a level above the normal. This rise of temperature caused by psychical activity is accompanied by a local warming of the brain, which was noticed for the first time by M. Schiff, later by Dorta (1890), and more especially by A. Mosso (1894). The daily curve of temperature, in so far as it is to a certain extent independent of muscular activity, but related to the alternation of wakefulness and sleep, is a proof of a relative hyperthermia caused by the activity of the nerve-centres and a relative hypothermia produced by their state of rest. It is a question of a rise or fall in the level at which the regulation of temperature occurs at different hours of the day and night.

IV. We have pointed out several times that the constancy of the average temperature of homoiothermic animals, mammals and birds, involves the possession by these animals of special means to regulate their temperature in such a way that the amount of heat produced equals that lost in the same time. We must now go more fully into the question of these means of regulation.

They may be divided into two groups: those regulating the loss and those regulating the production of heat. In the maintenance of the thermic balance much importance attaches to the means for the regulation of the loss of heat, *i.e.* those by which this loss is increased when the temperature of the body is raised, and diminished when the temperature is lowered below the normal average.

The heat developed by the body is partly used to warm the air inspired and the cold liquid and food taken, but the greater part of it passes into the environment by radiation from the surface of the body, evaporation of water from the skin and the lungs, and exhalation of carbon dioxide from the lungs.

According to the approximate calculations made by Helmholtz and Rosenthal the quantities of calories lost in twenty-four hours from these various sources in an adult are apportioned as follows:

1. Water 1500 grms., heated from 15° to 37·5°	=	34	calories
2. Food 1500 grms., heated from an average temperature of 25° to 37·5° C. (specific heat 0·8)	=	15	„
3. Air inspired about 15,000 litres, heated from 15° to 37·5° C. (specific heat 0·237)	=	80	„
4. Water discharged in the form of vapour, about 450 grms. (latent heat 0·592 calories)	=	266	„
5. Carbon dioxide discharged by the lungs, about 800 grms. (0·118 cal. per. grm.)	=	94	„
Total		489	„

Since the sum total of heat lost by an adult in a condition of equilibrium of thermic balance amounts on an average to 2400 cal., we may estimate the daily loss through the skin at about 1911 cal.

Mammals and birds possess natural means of reducing or delaying the loss of heat, which enable them to attain an average temperature which is very high in proportion to the quantity of heat developed by them. These means of defence against the loss of heat are the subcutaneous layer of fat and the fur or feathers with which the skin is covered. Man, having no fur, instinctively covers himself with clothes, which fulfil the same purpose as the fur of mammals and the feathers of birds. The layer of adipose tissue is a bad conductor, and diminishes the loss of heat from the muscles to the cutaneous surface; the fur, feathers, and clothes diminish the radiation of heat from the cutaneous surface to the surrounding air. Coverings, whether natural or artificial, raise the stratum of air which comes into immediate contact with the skin to a temperature somewhat over 30°. Since air is a bad conductor of heat, four times less than wool, it is easy to explain why the surface of the skin which is covered with clothes has a temperature varying from 33° to 35° C., while the exposed parts are much colder. If the fur of a dog or rabbit be removed by

shaving, there will be, according to the temperature of the environment, a more or less marked drop in their internal temperature. A man stripped of his clothing and in a state of rest cannot maintain his normal temperature unless the temperature of the environment be brought up to at least 27° (Senator). Rubner made special calorimetric researches in order to obtain direct confirmation of the importance of the cutaneous covering for reducing the loss of heat and keeping up the average temperature of the body. He found, for instance, that a normal guinea-pig lost by conduction and radiation 3.35 cal. per hour on an average; the same guinea-pig when shaved lost in the same time 4.47 cal., *i.e.* about 30 per cent more. He found the same held good for man: a bare arm at the ordinary temperature of the room lost about 30 per cent more heat than the arm covered with clothing.

When the temperature of the environment in which we live oscillates between 15° and 20° , as is the case in the temperate seasons and in the house, warm-blooded animals with their natural covering and man protected by suitable garments can maintain their average normal temperature at the same level; they do not need to make use of any special apparatus for regulating the heat, because the natural and artificial coverings moderate continually the loss of heat, and thus preserve an almost perfect equilibrium in the thermic balance. But when the outer temperature goes down or rises beyond those limits, as happens in winter and summer, the means for regulation are set in motion in order to maintain the normal temperature, the loss of heat is diminished or increased, and the production is varied in the reverse direction according to the need.

One of the chief means of regulating the loss of heat is the vasomotor nervous system; it is able to vary either directly or indirectly the supply of blood to the cutaneous vessels. The temperature of the skin depends on the quantity of blood supplied to it; it increases when the peripheral vessels dilate, and falls when they contract. In the former case the loss of heat at the surface of the body is increased, in the latter decreased.

Cold air stimulates the sensory organs of the skin, which transmit the stimulus to the vaso-constrictor centres and by reflex action cause the contraction of the cutaneous vessels, and thus the loss of heat by conduction and by radiation is diminished. Hot air, on the contrary, reflexly reduces the tonic action of the vaso-constrictor nerves of the skin, and causes a dilatation of the cutaneous vessels, so that the flow of blood in the periphery is increased; the increased conduction and radiation of heat to the environment cool the blood. We must also take into account another fact which makes the mechanism of regulation by means of the vasomotor system more perfect. When the peripheral vessels contract, a larger quantity of blood circulates in the deeper

parts, the viscera and muscles, the chief thermogenic organs; when, on the other hand, the peripheral vessels dilate, the quantity of blood circulating in the inner parts is decreased. In the former case the total production of heat due to the metabolism of the viscera and the muscular system must increase, while in the latter it is diminished. We therefore see that the vasomotor system contributes in two ways to the maintenance of a uniform body temperature: by regulating the loss of heat in the periphery, and the regulation of its production in the inner tissues. The latter fact demands a more detailed analysis.

Numerous experiments have proved that the processes of oxidation in the organism increase, within certain well-defined limits, when the outer temperature goes down, and diminish when it rises. Amongst well-known researches upon this subject we may mention those made on the guinea-pig by Pflüger's pupils, on the cat by Duke Carl Theodore of Bavaria, and on man by Pettenkofer, Voit, and Fredericq.

Colasanti and Ditmar Finkler, who made experiments on guinea-pigs under Pflüger's direction, found that when these animals were exposed to a temperature which was gradually raised from 3° to 21° , they consumed a steadily decreasing quantity of oxygen per hour and per kgrm. of their weight. Duke Carl Theodore of Bavaria observed that the carbon dioxide discharged by the cat steadily decreased as the outer temperature was raised from -5.5° to $+30.8^{\circ}$. Pettenkofer and Voit proved, in the case of a young man weighing 71 kgrms., the gradual decrease in the quantity of carbon dioxide and nitrogen discharged when the temperature of the environment was raised from 4.4° to 30° . Fredericq (1882), experimenting on himself, found that in the morning in a fasting condition, and at a temperature of 15° - 20° , he absorbed 4 to 5 litres of oxygen in fifteen minutes. When, however, he exposed himself naked to a temperature of 10° , the oxygen absorbed in the same length of time increased to 5.5 and even to 6 litres.

From this and other researches made by various investigators, we may draw the general conclusion that the organic combustion, on which the production of heat depends, increases or decreases according as the outer temperature falls or rises within certain limits, which vary according to the animals experimented upon. Homoiothermic animals therefore possess a *mechanism regulating the production of heat*, which, in conjunction with the *mechanism regulating the loss of heat*, tends to preserve the equilibrium of the thermic balance.

We must now define more accurately the limits of the efficiency of the regulation of the production of heat, and determine how it serves to protect us from either cold or heat.

In the first place it is necessary to remember that cold does

not stimulate organic combustion when it acts directly on the internal organs, on which thermogenesis mainly depends. The cooling of the inside of the body through the lungs or the stomach, for instance, when one breathes through a very cold metal tube, surrounded by ice, or drinks iced water, or when the stomach of a dog is flushed with iced water through a gastric fistula, does not cause an increase but rather a marked diminution in the gaseous respiratory exchange. Even when cold acts on the periphery of the body, it produces not an increase but a decrease in the respiratory processes of the internal tissues, if the cooling of the skin goes beyond the limits already given, *and lowers the internal temperature* of the animal (Ludwig and Sanders - Ern). It is this process which renders death from freezing possible in the very low temperatures of the polar regions or lofty mountain peaks. When warm-blooded animals are exposed under such conditions, they respond like cold-blooded animals, which possess no means of regulating their production of heat. Such a regulation only protects from cold within certain limits, which vary in different warm-blooded animals. In all cases it is effective only when the cold acting on the periphery of the body does not succeed in lowering the internal temperature of the animal below the normal.

It is evident that the thermic regulation which takes place in such cases works through the reflex action of the nervous system. The sensory organs of the skin, stimulated by the action of the low temperature, cause—through the intervention of the centres—an exaggeration of the internal respiration of the tissues, almost in proportion to the sensation of cold. Since the muscles, by reason of their preponderance and the intensity of their respiration, are the chief seats of the production of heat, we may hold with Pflüger that reflex action of the centres in the regulation of temperature involves especially the motor nerves of the muscular system.

While, therefore, the reflexes, acting on the blood-vessels, regulate the loss of heat, the reflexes acting at the same time on the muscles regulate the production. We know that the nerve-centres normally exercise a tonic reflex effect on the muscular system.

This tonic action cannot be dissociated from a continuous stimulation of the respiratory process, which takes place in the muscles independently of their contraction. C. Bernard proved by analysis of the gases of the blood that after the severance of the motor nerves the respiration of the paralysed muscles becomes less active than that of the normal muscles at rest, but connected with the cerebro-spinal centres. The clinical fact that in cases of hemiplegia the paralysed limbs become after a certain time colder than the limbs on the healthy side, independently of any active

contraction of the muscles on this side, seems to me to confirm this phenomenon. Pflüger considers that the sense of tension and rigidity in muscles exposed to external cold is in proportion to the exaggeration of the reflex tone which is associated with increased intensity of chemical change in the muscles. When the sensation of cold increases owing to the skin becoming colder, shivering in the form of trembling and spasms in the muscles begins by reflex action, and greatly increases the respiratory processes and the production of heat, and thus prevents the internal temperature of the body from falling below the normal. We have a good example of this in the effects of a cold shower-bath, which does not lower the internal temperature, but, on the contrary, quickly raises it one- or two-tenths of a degree. This is obviously the result of the shivering, *i.e.* of the convulsive muscular contractions, which, caused reflexly by the shower-bath, bring about a violent increase in the production of heat.

In addition to shivering caused by reflex action, Richet distinguishes shivering of central origin, due to the action of exogenous or endogenous poisons. One classical example will be sufficient. Injections of chloral or chloralose acting upon the nerve-centres cause narcosis in dogs, during which the temperature of the animal falls to 32° - 30° . When the effects of the intoxication pass off and the animal awakes, its temperature gradually rises as the result of the shivering accompanying its awakening. Richet found that during the narcosis, when there is no shivering, the animal discharged a much smaller quantity of carbon dioxide than during the shivering fit which accompanied the awakening. This is a direct proof that the shivering intensifies the chemical processes taking place in the muscles.

The means which serve to maintain the average temperature at an almost constant level involve in the case of *protection from cold an increase in the production of heat*; those which are intended for *protection against heat increase the loss of heat*. This is clear if we consider the fact emphasised by the researches of Voit, Page, and Fredericq, that when the temperature of the environment rises above 20° - 25° the processes of combustion in the organism do not decrease, as they should do in order to prevent the temperature rising above the normal, but increase, as is proved by the greater discharge of carbon dioxide; the organism can only protect itself against the heat by increasing the loss of heat either by acceleration of the cutaneous circulation, the secretion of sweat, or more rapid breathing.

The immediate effect of an excessive rise in the external temperature is a general dilatation of the cutaneous vessels; a larger quantity of blood circulates in the periphery of the body, where it becomes cooler, because the external temperature in the large majority of cases is lower than that of the circulating blood.

The dilatation of the vessels which takes place in these cases is greater than that which results from simple decrease in the tone of the vaso-constrictor nerves caused by reflex action. It is therefore probable that the excessive external heat, acting on the periphery and on the nerve-centres, stimulates the vaso-dilator system both reflexly and directly. It is certain that a rise in the internal temperature of the body is enough to cause an active dilatation of the cutaneous vessels. There is a marked increase in the production of heat after taking hot food or drinks, during the process of digestion, and during hard muscular work. This increase is proved by the larger quantity of carbon dioxide discharged and of oxygen absorbed by the lungs. This increased production of heat, however, only causes a very slight rise in the internal temperature, because there is at the same time an increase in the loss of heat owing to the flushed condition of the skin, produced by the action of the vaso-dilator system. The efficacy of this heat-regulating mechanism is clearly proved by the fact that the taking of food and its digestion have little or no influence on the regular course of the daily curve of temperature.

Whenever the causes of the heating of the body become more intense, as for instance when the external temperature rises above the internal temperature of the body, we notice, in addition to the diffuse reddening of the skin, a more or less great secretion of sweat, the evaporation of which is the only efficient means of cooling the skin. In such cases the dilatation of the cutaneous blood-vessels not only fails to cool the body, but actually tends to heat it. The evaporation of sweat under such circumstances causes a rapid loss of a large quantity of heat. One grm. of water at 38° , the average temperature of the blood, absorbs during vaporisation about 580 small calories, *i.e.* the amount of heat required to raise the temperature of 580 grms. of water 1° . The heat-regulating efficacy of the evaporation of sweat is clearly proved by the fact that a man can remain without distress for some time in the so-called *laconium* of the new Roman baths, where the air is dry and heated to 60° . He could not bear such a temperature even for a minute if the air were damp instead of dry, because the moisture would prevent the rapid evaporation of water from the skin and the pulmonary passages, which is essential if the temperature is to be prevented from rising to a point incompatible with life. For the heat-regulating function of the skin, especially in relation to the protection of the organism against heat, and for the dependence of the secretion of sweat on the nervous system, the reader should consult Vol. II. Chap. IX. pp. 480-499. In man and in all animals in which the capacity to sweat is well developed, such as monkeys, horses, and other mammals, cutaneous perspiration, both insensible and sensible, is the main protection against heat; in animals which do not sweat, such as the larger number of mammals and

all birds, pulmonary transpiration is the chief means of defence against heat.

Ackermann (1867) called attention to the fact, already known to Hippocrates, that pulmonary ventilation can cool the blood. When the external temperature rises, respiration becomes more frequent and more rapid (*heat tachypnoea* or *polypnoea*), cools the lungs, and increases the loss of heat owing to the greater discharge of water-vapour from the lungs. These researches were resumed and carried further by Fick, Goldstein, Gad, and more especially by Richet (see Vol. I. Chap. XIII. p. 470), who in 1885 proved by numerous experiments the heat-regulating function of *tachypnoea* in dogs, which do not sweat.

Tachypnoea is generally a reflex phenomenon independent of the vagus nerves and caused by stimulation of the cutaneous nerves. Richet observed in a small dog that respiration, after section of the vagus nerves, became very slow and difficult, five respirations per minute. After being kept for several hours in an incubator, the temperature of the animal remained unaltered (39.1°), and it breathed 120 times a minute. Thus after section of the vagus nerves, the dog could maintain the normal temperature in the same way that a healthy dog exposed to the sun in summer begins to pant in a few minutes. Tachypnoea not only keeps the temperature normal, but even at times, according to Richet, causes it to fall slightly, "comme si la régulation par production de froid avait dépassé le but et produit plus de froid qu'il n'était nécessaire."¹

Heat tachypnoea is central in its origin when it is due not to an excessive rise in the external temperature, but to an abnormal increase in the thermogenic processes of the organism, as in fever. It can be experimentally produced in various ways: by general tetanisation with induced electric currents; by the injection of toxic substances which produce a rise in the temperature of the animal by causing a rapid increase of combustion in the muscles. Richet found that whenever the bodily temperature of dogs rose above 41.7° , the frequency of breathing invariably increased enormously; it may rise from 80 to 400 respirations per minute. The dog in such circumstances breathes with its mouth wide open and its tongue hanging out.

The following experiment made by Richet seems to me to afford conclusive proof of the efficacy of tachypnoea in regulating the temperature of dogs. If two dogs be exposed to the sun, one being normal, the other curarised, artificial respiration unvarying in rhythm being carried out on the latter, it will be found that the temperature of the normal dog will not rise; on the contrary, it will fall slightly after a few hours, owing to the over-cooling

¹ "As if the regulation by the production of cold had surpassed its aim and produced more cooling than was necessary."

action of tachypnoea, whereas the temperature of the second dog will gradually rise from 40° to 43° .

V. Our study of the mechanism regulating the temperature leads to the general conclusion that it is a function of the nervous system. Numerous experimental lesions of the spinal cord and brain of the higher animals, and many lesions of these centres due to accident or disease in man, have shown that *hypothermia* or *hyperthermia* may be caused by a disturbance of the regulation of temperature, produced respectively by destruction or stimulation of these centres.

The *hypothermia* following transverse section of the spinal cord (C. Bernard and others) is readily explained as the effect of the muscular paralysis, which lessens the production of heat, and the paralysis of the blood-vessels, which increases the loss of heat.

The cases of accidental or experimental injuries to the spinal cord which produce *hyperthermia* are more obscure. Brodie (1837) noticed that a fracture of the spinal cord in the neck caused the temperature of the rectum to rise to 43.9° C. Billroth (1870) found that the temperature rose to 42.2° after fracture of the sixth cervical vertebra; in a similar case Simon observed a hyperthermia of 44° ; and Frerichs recorded a temperature of 43.8° in consequence of the fracture of the fifth and sixth cervical vertebrae.

Sometimes injuries to the cervical spinal cord cause hypothermia instead of hyperthermia. Fischer found in two cases a lowering of the temperature to 34° and 30.2° respectively. Breadburg (1885), in a case of cervical paraplegia, noticed marked oscillations in the temperature, which varied from 35° to 42° .

Physiological experiments were made with a view of confirming these clinical observations. Fischer found that if instead of destruction or transverse section of the cervical portion of the spinal cord, a simple puncture was made in it, the temperature of a dog rose 1.7° . After crushing the cervical region of the cord, Naunyn and Quincke observed that the temperature rose to 40° in five hours, and to 42.3° in a day.

The results of experiments on the medulla are not so concordant. After transverse section of the bulb, Lewitsky (1869) found that hypothermia constantly set in; Bruck and Gunter (1870), on the other hand, obtained in 23 cases eleven positive and twelve negative results. Schreiber (1874) noticed a rise in temperature of 2° , when he prevented the animal from becoming cold by covering it with blankets. He considered that the severance of the bulb or pons Varoli augments both the production and the loss of heat, and that the latter exceeds the former, and thus hypothermia is the result. Wood, on the contrary (1880), found that injuries to the pons were almost always followed by hyperthermia; the production exceeded the loss of heat.

Wood made numerous experiments to determine the effects of cerebral lesions upon the temperature. Eleven times he found hypothermia, and fifteen times hyperthermia. He came to the conclusion that *the only cerebral centre* which can act on thermogenesis without acting on the vasomotor centres and nerves is situated in or close to the pons, and probably acts as a *thermo-inhibitory centre* on lower centres situated in the spinal cord. He was unable to prove that injury or stimulation of the brain necessarily caused a rise of temperature. This last fact was proved for the first time by the experiments made simultaneously by Richet and I. Ott in 1884. A prick given with a pin or stiletto in the front part of the brain of a normal rabbit was enough to send its temperature up 2° in less than an hour, without the production of any other abnormal effect, such as contractions or paralysis. If the prick be repeated next day in the same part of the brain, the hyperthermia may reach 42.5° in fifty minutes. Sometimes, but not invariably, this hyperthermia coincides with an increased excitability of the brain; the animal runs about, or starts at the slightest sound.

Aronsohn and Sachs (1884) tried to ascertain which parts of the brain will cause hyperthermia when they are punctured; they found them to be the *front portions of the corpora striata*, and regarded these parts as the seat of a *special heat centre*. Girard, however, who made various researches (1888) of the same kind, only accepted this conclusion with important reserves, and summed up his work in the statement "qu'il n'est pas permis d'admettre l'existence dans l'encéphale des animaux à température constante d'un centre thermique unique."¹

An experiment carried out by Corin and van Beneden on pigeons in 1886 proves that the corpora striata cannot be regarded as the seat of a specific heat centre, or as a means of heat regulation. After the ablation of the cerebral hemispheres, the capacity to regulate the temperature remains unaltered in these animals; the daily curve of temperature takes the same course as in normal pigeons; the calorimetric determinations give values but little lower than in normal birds. Goltz in his famous brainless dog did not find any complete loss of capacity to regulate the temperature, though the animal lost more heat than usual (Vol. III. Chap. IX. p. 507).

The numerous researches made by Hale White (1890-91) on rabbits led him to support the view taken by Aronsohn and Sachs. He considers that a rise in temperature is caused especially by puncture of the corpora striata, sometimes also by puncture of the optic lobes. No marked change of temperature is caused by pricking the anterior or posterior cerebral convolutions, the

¹ "That it is not permissible to admit the existence of a special heat centre in the brain of warm-blooded animals."

white matter round the corpora striata or the cerebellum. He, however, admits that injuries to the peduncles of the brain cause a rapid rise in temperature. It also follows from the records of his experiments that injury of the convolutions of the brain may cause marked disturbances in the regulation of temperature—in one such case he recorded a temperature of 41.3° . His opinion that the corpus striatum is *the true thermogenic organ* of homoiothermic animals does not appear to me tenable.

At the same time (1890) I. Ott announced as the result of his researches upon the brain that there are a number of *cerebral heat centres*: one in front of and under the lenticular nucleus, a second in the convexity of the caudate nucleus, a third in the *lamina cornea*, a fourth in the front and inner part of the optic thalamus, a fifth in the Rolandic area of the cerebral cortex, and a sixth in the cortex in the Sylvian fissure.

If, however, there are six cerebral heat centres in the rabbit and the cat—twelve, indeed, since they are symmetrical—it is impossible, when we come to think it over, to localise them exactly, and we are thus led to the conclusion formed by Richet that all parts of the brain, as the result of lesions more or less deep and irritating, can produce a more or less definite hyperthermia.

Richet cauterised superficially the cerebral cortex of dogs which were kept motionless, and found that the temperature of the rectum rose 0.5° and even 0.75° . F. Tangl (1895) found that a puncture in the front part of the optic thalamus of the horse made the temperature rise in one case to 40.4° , and in another to 40.8° ; in two other horses there was no rise of temperature when the puncture had not touched the optic thalamus. In many cases of traumatism and cerebral tumours, surgeons have observed hyperthermia uncomplicated by sepsis or convulsions.

In a case of fracture of the skull with haemorrhage compressing the temporo-occipital region, Broca saw the temperature rise 3° in a few hours; in another case the temperature rose 5° in six hours and a half. After ablation of an angioma of the brain, the temperature rose to 42.1° ; in a case of cysts to 41.8° ; in one of tumour at the base of the skull to 41.9° ; and in one of parieto-occipital tumour to 42° .

When injuries causing irritation of the brain do not cause any marked change in the normal temperature, the conclusion must not at once be drawn that they have caused no increase in the organic processes of combustion, since the increase in the heat produced may be balanced by an equal increase in the heat lost.

The very definite records of hyperthermia following different injuries to the brain, show that the thermogenic functions of the brain are no less marked in man than in the higher animals in

general. Considerable rises in temperature have also been observed in medical cases of haemorrhage and softening of the brain uncomplicated by convulsions. Hutin recorded a hyperthermia of 42.5° in a patient three days after haemorrhage into the corpus striatum on one side.

Puncture of the brain in animals always causes a certain increase in pulmonary ventilation, although it does not always take the form of polypnoea or tachypnoea. This explains the fact noticed by Witrowski (1891), that after the brain of a rabbit had been punctured, although the production and discharge of carbon dioxide increased, there was a slight diminution in the quantity of this gas found in the blood.

Richet, who ascertained calorimetrically the heat discharged in the same unit of time by a normal rabbit, and by the same rabbit after cerebral puncture, found in 24 cases that the heat lost was increased on an average 25 per cent after the puncture. Aronsohn and Sachs noticed an increase in the processes of combustion after the puncture; they deduced this increase from the direct determination of the quantity of carbon dioxide discharged before and after the cerebral injury.

When therefore puncture, or any other irritating lesion, does not cause hyperthermia, it indicates that the increase in the production of heat is compensated by the simultaneous increase in the loss of heat, either by vasomotor paralysis or by increased evaporation from the lungs. When, on the other hand, the puncture causes hyperthermia, it follows that the production has increased proportionately more than the loss of heat; this is always the case in the hyperthermia which as a fundamental symptom accompanies the process of fever.

In fever there is always exaggerated production accompanied by increased loss of heat; the former process predominates over the latter in proportion to the abnormal rise in the temperature. The heat-regulating centres of a patient suffering from fever regulate the temperature at a higher level than the normal—a fact first recognised by Liebermeister. Indeed the daily curve of temperature usually pursues the same course in fever as the normal curve (Jürgensen). In the patient with fever there is always a certain proportion between the production and the loss of heat: an increase in the former corresponding to an increase in the latter (Lövit). With a febrile temperature of 40° there is a loss of heat 20-25 per cent greater than in a healthy person whose temperature is regulated at 37° (Liebermeister). If this increased loss of heat does not lower the patient's temperature, it follows that the production of heat is 40-50 per cent greater than in a normal person. The loss of heat may therefore be considered to have decreased in proportion to the increased thermogenesis; this confirms the old theory set up by Traube, who

considered retention of heat to be a characteristic of fever, specially noticeable in the period of rigor or shivering.

Richet rightly lays stress on the fact that there is an enormous increase in the production of heat during hard muscular work, this increase amounting sometimes to as much as 200 per cent more than the normal. The worker's temperature, however, only rises about a degree or a part of a degree above normal, and quickly returns to its usual level. This is explained by the fact that the nerve-centres of the worker keep the temperature at the normal point, so that the great increase in the production of heat is counterbalanced by an equivalent loss in the form of external work and of heat by evaporation from the lungs and skin. In the patient with fever, on the contrary, an increase in the production of heat which never exceeds 50 per cent causes the temperature to rise to 40° - 43° , because in fever the regulation of temperature by the nerve-centres takes place at an abnormally high level, so that the moderate increase in production is associated with a much smaller increase in the loss of heat. This shows clearly that *the essential internal condition causing the rise of temperature during the process of fever is a functional disorder of the nerve-centres on which the regulation of temperature depends.*

All we have learnt in the last two chapters with regard to *the exchange of material and energy* in man and the higher animals is closely connected with the question so much discussed in times past: *whether there exist centres and nerves which are specifically trophic, i.e. the sole function of which is the regulation of the nutrition of the tissues; and centres and nerves which are specifically thermic, i.e. only for the regulation of thermogenesis.* The numerous observations and experiences we have quoted, clearly prove that the nervous system regulates both the nutrition of the tissues and the production of heat. They also show that so far there are no conclusive observations or experiments to prove the existence of centres and nerves of an *exclusively trophic or thermic nature.*

I am of the opinion that we may come to the following general conclusion, which I formulated as early as 1889, in my monograph on fasting:

"The regulation of nutrition and thermogenesis, of the processes of integration and disintegration, or more generally of the exchange of material and energy, whether of each part or of the organism as a whole, *is the fundamental function of the nervous system, considered as a whole and a unit, and not of one or other part or segment.*"

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CHAPTER III

THE THEORY OF HUMAN NUTRITION

SUMMARY.—1. Composition of the principal articles of food of animal and vegetable origin. Theory of the *normal diet* for adult man, deduced from the statistics of nutrition drawn up by Voit, Atwater, and Tigerstedt. 2. Criticism of the statistical method. Experimental researches of Hirschfeld, Kumagawa, Klemperer, Sívén, Caspari, and Albu, proving that nitrogenous equilibrium can be maintained on a diet considerably less abundant than that in common use. 3. Fletcher's case scientifically illustrated by Chittenden. 4. Chittenden's recent experimental researches on three groups of persons, proving the theory of *reduced* or *economical nutrition*. 5. The question of vegetarianism. 6. Variations of diet in relation to sex, the stage of growth (anaplasia) and old age (cataplasia). Bibliography.

TAKING as our basis the results of researches upon exchange of material, we were able to classify food substances in groups in accordance with the criteria of physiology, that is, according to their different uses in the organism (Chap. I. 12). In the discussion on the exchange of energy of the whole organism we ascertained the heat value of the principal organic compounds in foods, the potential energy inherent in their chemical composition (Chap. II. 1). We have therefore gained a fair knowledge of the conditions on which the material and dynamic equilibrium of the animal economy depends, and may venture to attempt the solution of the difficult and at present much disputed problem of the diet best suited to normal man at different ages, in different occupations and under different conditions of life. It is an eminently practical problem, of equal interest to the physiologist, the hygienist, the doctor, and the sociologist.

I. With regard to the diet required to keep a man in good health, we may conclude from the results arrived at in the two preceding chapters that he must take every day a certain quantity and quality of food-stuffs suitable for the development, nutrition, and restoration of the tissues (proteins); and containing a sufficient quantity of potential energy for the exercise of the various functions (fats and carbohydrates) and finally supplying the right stimulus to the activity of the digestive organs without tiring them unduly (condiments).

In the choice of food, man and animals alike are, as a general

rule, guided by the *instinct of self-preservation*, by the *need of food*, which is stimulated by special internal sensations called *appetite* or *hunger*, according to the degree of intensity (Vol. IV. Chap. II. 4). Herbivorous or frugivorous animals derive their nourishment from vegetables; carnivorous from herbivorous or other carnivorous animals; man is usually regarded as omnivorous, because he lives sometimes on vegetable, sometimes on animal food, more often on both, according to the climate, the kind of food most easily obtainable, and the flora and fauna of the region in which he lives.

In tropical countries he lives almost entirely on vegetables, in the frigid zones on meat and animal fat, and in temperate regions on a mixed diet.

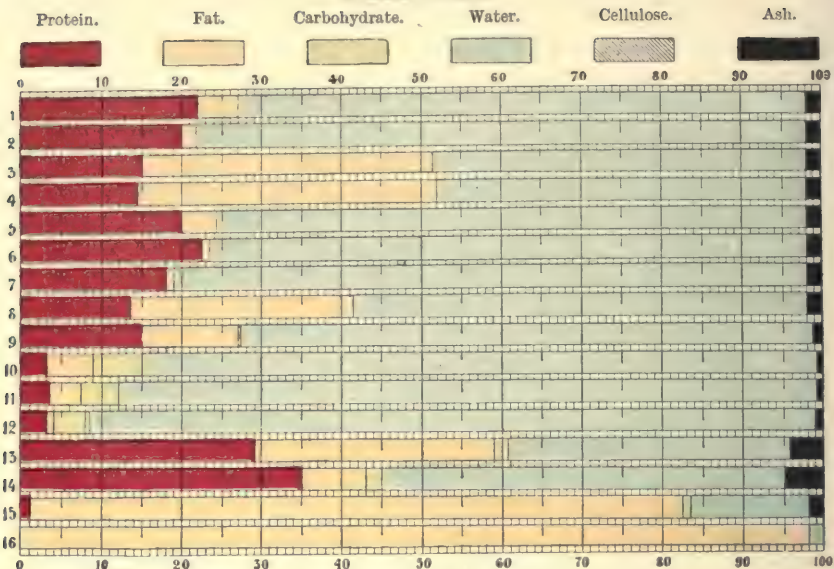
The nitrogenous and non-nitrogenous food substances necessary for the nutrition of men and animals, are found in varying quantities in the different natural foods, both animal and vegetable. Proteins and fats predominate in animal food, carbohydrates in vegetable food, as will readily be seen from a glance at the diagram of the percentage composition of the groups of food substances found in the complex animal and vegetable food most used by man in our temperate climate (Fig. 16).

In order to solve the practical problem of the choice of foods best suited to meet the alimentary requirements of man, or, in other words, to ascertain the normal diet of adult men, physiologists, hygienists, and doctors have usually had recourse to statistics. After examining the quality and quantity of the animal and vegetable food taken daily by a large number of persons in good health, they have found the average quantities of *protein*, *fat*, and *carbohydrate*, and considered these to represent the *normal daily diet* of adult man.

The value of the statistical method rests entirely on the assumption that in the choice and quantity of his food, man, like animals in general, is guided by instinct and experience, and that he has learned to desire and take what is good for him and to reject or refuse what is harmful. Von Noorden, in his recent treatise on the pathology of metabolism (1900), expresses this idea in the following words: "If the knowledge deduced from the systems of nutrition selected by different races of their own accord, be regarded as a biological law, we are undoubtedly justified in assuming that mankind, in the course of about four thousand years of struggle for existence, has established a suitable diet and the proper standard of protein."

The most reliable statistics for our purpose are those derived from careful inquiry into the food of persons free to choose it for themselves. The results of inquiries into the diet of persons living in a community, such as soldiers and sailors, school children, pupils in art or technical institutions, and prisoners, though far

ANIMAL FOODS.



VEGETABLE FOODS.

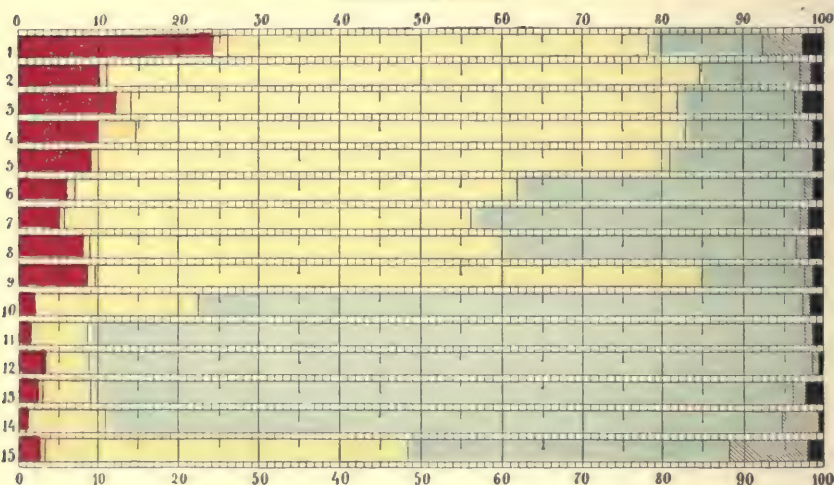


FIG. 16.—Diagram showing the percentage composition of *Animal Foods*.

- | | | |
|---------------------|---------------------------|-------------------------|
| 1. Lean beef. | 7. Pike. | 12. Cow's milk skimmed. |
| 2. Lean veal. | 8. Eel. | 13. Fat cheese. |
| 3. Very fat mutton. | 9. Hen's egg. | 14. Lean cheese. |
| 4. Fat pork. | 10. Woman's milk. | 15. Ordinary butter. |
| 5. Lean chicken. | 11. Cow's milk (natural). | 16. Lard. |
| 6. Game. | | |

Vegetable Foods.

- | | | |
|---------------------------------------|--|-------------------|
| 1. Vegetables (peas, beans, lentils). | 7. Rye bread. | 11. Cauliflowers. |
| 2. Fine wheat flour. | 8. Brown bread as given to Italian soldiers. | 12. Mushrooms. |
| 3. Rye flour. | 9. Rice. | 13. Spinach. |
| 4. Maize flour. | 10. Potatoes. | 14. Fresh fruit. |
| 5. Maccaroni and wheat pastes. | | 15. Dried fruit. |
| 6. Fine wheaten bread. | | |

easier to obtain, are regarded as less valuable, since such persons cannot choose their food freely, and the objection may consequently be raised that their diet is arranged according to the theories of the individual at the head of such communities or institutions.

Before proceeding to a minute criticism of the scientific value of this statistical method, let us examine the results obtained by it as regards the definition of the *normal human diet*.

Voit, in his famous lecture at Munich in 1875 before the *Public Health Congress*, proposed 118 grms. of protein, 56 of fat, and 500 of carbohydrate as the normal diet of an average working man; this calculation was based on the results of a large number of observations. He regarded as an average working man a robust man weighing 67 kgrms., able to accomplish daily in nine to ten hours a considerably larger amount of muscular work than a tailor, though less than a blacksmith, and much the same amount as a mason or a carpenter.

The heat value of such a diet amounts to 3055 calories, which, if we deduct the heat of combustion of the faeces, estimated by Tigerstedt at 10 per cent, gives a total of 2749 calories.

In the case of men doing heavier work, Voit finds that the daily requirements are greater, *i.e.* 145 grms. of protein, 160 of fat, and 450 of carbohydrate. This diet represents a total value of 3370 calories.

Atwater (1902-3), as the result of still more numerous observations, estimated the normal diet of workmen doing a moderate amount of work at 125 grms. of protein, together with such quantities of fat and carbohydrate as would raise the total heat value to 3500 calories. He considered that workmen engaged in harder work required a diet of 150 grms. of protein, and an amount of fat and carbohydrate sufficient to raise the total to 4500 calories.

These approximate data are generally accepted by physiologists and hygienists. Tigerstedt, one of the greatest authorities, and the most recent writer on the subject (1909), considers the number of calories represented by Voit's average diet too low, and advocates that of Atwater. He notes that the dietary established in 1891 in the Swedish prisons for those condemned to penal servitude corresponded closely to what Voit considered a normal average, but the convicts were allowed to spend part of their weekly earnings in supplementing the ordinary diet. Later, owing to various prison regulations, the convicts were almost entirely forbidden to spend their earnings in this way, but after a short time this prohibition had to be removed, the ordinary diet having been proved to be inadequate. It would be more accurate to say that the complaints of the prisoners were accepted as proof of the insufficiency of the diet.

With regard to the food requirements of the average working

man, Tigerstedt remarks that, if we admit (i) that a day's work of 100,000 kgrimeters cannot be considered excessive for an adult man, (ii) that the material exchange of a man at rest is equivalent to 2350 calories, and (iii) that in muscular work 25 per cent of the energy expended is used, we are led to the conclusion that the workman must consume 941 calories more, which, added to 2350, gives a total of 3291 calories. If to this number we add the 10 per cent which, according to Tigerstedt's calculations, are lost in the faeces, we have a total of 3650, representing the energy value of the whole of the food of an average workman. This figure is much nearer the higher estimate of Atwater than the lower one of Voit.

The sum total of the observations collected by Atwater and Tigerstedt relating to the food voluntarily chosen by workmen proved that the general diet, and the corresponding energy value, were in some cases considerably lower, but in a larger number of cases much higher than the average given above. This depends not merely on the fact that a very different degree of intensity of work is required in different trades and professions, but also on the fact that different individuals following the same trade accomplish a very different amount of work, and more especially on the fact that the alimentary requirements of different individuals vary greatly, even when they do an equal amount of work. An *average diet* is not suited to all alike, and should be regulated in both public and private institutions according to individual requirements.

Tigerstedt classifies the food requirements of workmen in seven groups according to their total energy value as shown in the following table :

1. 2000-2500 calories.	5. 4000-4500 calories.
2. 2500-3000 ,,	6. 4500-5000 ,,
3. 3000-3500 ,,	7. Over 5000 ,,
4. 3500-4000 ,,	

In order to show clearly the distribution of the food substances in the dietary of different individuals, Tigerstedt gives in the two following tables a large number of observations of diets freely chosen. The first table shows the diet of American workmen, drawn up from the investigations made under Atwater's supervision according to a strictly uniform system of observation, and published in the *Report of the Minister of Agriculture of the United States*. In the second table are collected the more or less accurate and complete observations published by various European physiologists and hygienists.

[TABLE

TABLE I.

Groups.	Protein.			Fat.	Carbohydrate.	Calories.		Cal. per kilo. body-weight = 70 kilos.	Number of Observations.
	Animal.	Vegetable.	Total.			Taken.	Utilised.		
I. {	Max. 91	60	131	125	395				18
	Min. 2	18	35	34	181				
	Mean 50	36	86	81	295	2135	1921	27	
II. {	Max. 82	62	129	163	458				23
	Min. 8	24	49	56	255				
	Mean 47	41	88	108	345	2779	2501	36	
III. {	Max. 97	82	152	182	563				36
	Min. 4	32	52	65	314				
	Mean 56	47	103	125	409	3262	2936	42	
IV. {	Max. 133	107	199	200	701				19
	Min. ...	36	66	71	304				
	Mean 68	57	125	137	476	3738	3364	48	
V. {	Max. 103	81	164	210	649				16
	Min. 10	48	74	95	412				
	Mean 54	62	116	158	538	4180	3762	54	
VI. {	Max. 111	73	181	269	708				7
	Min. 25	49	80	118	485				
	Mean 86	59	145	195	557	4692	4223	60	
VII. {	Max. 128	90	204	283	723				7
	Min. 27	60	93	173	617				
	Mean 71	75	146	235	666	5511	4954	70	

TABLE II.

Groups.	Total. Protein.	Fat.	Carbo- hydrate.	Calories.		Cal. per kilo. body-weight = 70 kilos.	Number of Observa- tions.
				Taken.	Utilised.		
I. { Max. Min. Mean	118 57 82	85 11 44	469 290 362	2229	2007	29	} 13
II. { Max. Min. Mean	160 65 104	113 16 60	568 254 464	2889	2600	37	
III. { Max. Min. Mean	163 82 127	141 27 85	730 310 466	3222	2900	41		} 16

TABLE II.—*Continued.*

Groups.	Total Protein.	Fat.	Carbo-hydrate.	Calories.		Cal. per kilo. body-weight = 70 kilos.	Number of Observations.
				Taken.	Utilised.		
IV. {	Max. 152	162	730				} 11
Min. 112		27	359				
Mean 136		93	556	3702	3332	48	
V. {	Max. 182	205	788				} 7
Min. 133		40	391				
Mean 162		135	569	4252	3827	55	
VI. {	Max. 225	145	829				} 5
Min. 138		77	677				
Mean 182		106	737	4752	4277	61	
VII. {	Max. 218	306	1328				} 9
Min. 112		25	431				
Mean 166		156	952	6037	5433	90	

On the ground of these statistical data Tigerstedt comes to the conclusion that a daily diet with an available energy value below 2000 calories must be considered insufficient for a workman. He does not, however, deny that there are a number of observations upon individuals who were able to work on a much smaller diet, but these observations were of too brief a duration and were made on too small a number of cases to prove that such a diet, falling below that fixed by Voit as the average, was sufficient to maintain a satisfactory and lasting state of nutrition.

II. The average diet, based upon the above statistics collected by Voit, Atwater, and Tigerstedt, was generally accepted by physiologists, hygienists, doctors, and economists until a few years ago. Further consideration shows that the value of these data consists simply in a pure statement of facts, from which it is not strictly correct to deduce the physiological laws of nutrition under the varying need of food, the basis of the physical, intellectual, and moral well-being of nations. The data give us an idea of the composition, quantity, and total energy value of the articles of food selected freely and consumed by the Europeans and the Americans included in the scope of the inquiry, but fail to prove that their dietary represents the ideal, the one best adapted to maintain permanently the condition of nutrition and energy most advantageous to the human economy. If it be true that animals living under natural conditions are guided by instinct in the selection of food, the same cannot be said of civilised races, in whom primitive instinct has not free play, but has been forced into the background by appetites derived from the most highly developed psychical

activity. It is undeniable that the regimen adopted by our race is to be attributed, at least in part, to the influence of bad habits strengthened by heredity in the course of many generations, such as the use and abuse of alcohol, tobacco, and certain alkaloids, which are certainly not included in the category of the principal natural articles of food.

"Sir William Roberts," as Chittenden remarks, "said that the palate is the *dietetic conscience*, but he also added that degenerate palates are very numerous; and we may reasonably ask ourselves whether an erroneous system of life has not as a general rule perverted our dietetic conscience. The habit of satisfying our appetite on every occasion, of obeying every fancy of our palate even to satiety, taking little or no account of the physiological needs of our body, may easily and naturally have constituted a false rule of life, far removed from the true laws of nutrition."

In order to find a scientific foundation for the theory that the large majority of our nations eat much more than is physiologically useful, it was necessary to employ the test of experiment.

Instead of studying the diet of persons who are free to choose at will both the quality and quantity of their food, those persons should be studied who voluntarily submit themselves in the laboratory to a special regimen.

As early as 1888 Hirschfeld, wishing to determine on himself the smallest quantity of protein necessary for nitrogenous equilibrium, obtained the following result: During his first series of researches he took daily an average of 4.73 grms. of nitrogen, 135 of fat, 266 of carbohydrate, and 54 of alcohol. He found that from the fourth to the eighth day of this diet he discharged daily in the urine and faeces an average of 6.65 grms. of nitrogen. There was therefore a definite daily deficit of nitrogen. During another series of investigations he took an average of 7.44 grms. of nitrogen (= 47 grms. of protein), 165 of fat, 354 of carbohydrate, and 43 of alcohol, and found that from the fifth to the eighth day he discharged 7.53 grms. of nitrogen. With this diet, which, compared with Voit's average, is very poor in protein, he almost maintained nitrogenous equilibrium.

Similar results were obtained by Kumagawa and Klemperer (1889). The former in nine days took an average of 8.75 grms. of nitrogen (= 55 grms. of protein), 2.5 of fat, 370 of carbohydrate, and discharged on an average only 8.10 grms. of nitrogen, that is, he retained daily 0.65 gm. of nitrogen. Klemperer experimented on two young workmen of 20 and 28 years of age. Their diet consisted on an average of 5.28 grms. of nitrogen (= 34 grms. of protein), 264 of fat, 470 of carbohydrate, and 172 (!) of alcohol. From the sixth to the eighth day the average discharge of nitrogen was 4.60 and 3.91 grms. respectively, therefore in this case also 0.68 and 1.37 grms. of nitrogen were retained.

The total energy value of the diets tried by Hirschfeld, Kumagawa, and Klemperer was, as Munk remarked, extremely high, far more than is necessary for a person doing a moderate amount of work. It might therefore be supposed that nitrogenous equilibrium on a diet, poor in protein, is only obtained when an excessively large number of calories is supplied at the same time. This view was, however, disproved by Sivéñ (1899).

Sivéñ experimented upon himself for several days with isodynamic diets, which were gradually made poorer in protein and correspondingly richer in non-nitrogenous substances. From the following table it will be seen that he obtained nitrogenous equilibrium on an extremely small quantity of protein, without increasing excessively the sum total of calories.

Series of Researches.	Duration of each Series in Days.	Daily average of—			Balance of Nitrogen in Grms.
		Nitrogen intake in Grms.	Calories.	Nitrogen discharged in Grms.	
1	7	12.69	2478	11.30	+1.39
2a	3	10.44	2493	10.40	+0.04
2b	6	10.35	2505	9.36	+0.99
3	6	8.71	2486	7.98	+0.73
4	6	6.26	2477	6.36	-0.10
5	4	4.52	2444	4.95	-0.43
6	7	2.47	2440	3.51	-1.04

In a successive series of researches (1901), Sivéñ reduced from day to day the quantity of nitrogen introduced from 18 to 2.64 grms. The nitrogen discharged in the urine and the faeces was 4.88 grms. on the fourth day, and 4.06 grms. on the seventeenth. After increasing the daily quantity of nitrogen introduced to 4.02 grms., he obtained as an average of four days a loss of 4.30 grms. of nitrogen, approaching, it will be seen, nitrogenous equilibrium.

W. Caspari (1901) could not confirm upon himself the results obtained by Sivéñ, but that this was not an isolated case, as he suspected, is proved by the earlier researches of Hirschfeld, Kumagawa, and Klemperer.

All these scientifically conducted experiments prove that the adult man can maintain nitrogenous equilibrium on a diet containing a much smaller quantity of protein than that usually regarded as the average, and this he can do without being obliged to add an excessive quantity of heat-producing substances of non-nitrogenous origin in order to raise the total energy value of the diet above the normal. Why have these facts not been taken into account in the determination of the average diet best suited to the adult man who does a moderate amount of muscular and nervous work?

For two reasons: (a) because the investigation of the effects of meagre nutrition only applied to a very small number of persons, a fact which gave ground for suspicion that these cases were merely exceptions to the rule; (b) because these researches extended over too short a period, and could not therefore afford a decisive proof of adequate nutrition for all the requirements of muscular and nervous work during ordinary daily life.

In order to depreciate the value of these objections, some writers have laid stress upon the fact that many Asiatic races consume a much smaller daily quantity of protein than Europeans and Americans. The staple diet of the inhabitants of India, China, and Japan is rice which, as is shown by Fig. 16, contains a very small amount of protein. Here it is not a question of isolated cases, but of many millions of human beings who have lived normally for at least four thousand years on a much smaller quantity of protein than that consumed by Europeans and Americans on whom Voit, Atwater, and Tigerstedt founded their doctrine of human nutrition. Against these persuasive arguments it may be pointed out that we have no *accurate statistical data* proving that Asiatics require for the performance of work corresponding to that of Europeans a smaller quantity of protein in proportion to their body-weight and nervous and muscular activity, or that this smaller quantity may not be compensated by a larger quantity of non-nitrogenous substances, and thus a larger sum total of calories be available.

Everything we have said so far leads us to the unsatisfactory conclusion that the problem of the nutrition best adapted to the human race has not yet been solved. In this connection, however, the most recent researches of Russell and Chittenden (1904) seem to me of great importance, and a decided step towards the solution of this complex problem.

III. Chittenden in 1903 investigated during several months in his laboratory the diet and mode of life of Horace Fletcher, an enthusiastic and intelligent advocate and preacher of economy in nutrition, which he had practised for some years with beneficial results to his mental and physical vigour, and to the great improvement of his general health. He had gradually succeeded in satisfying his appetite completely with an extremely scanty diet, and no longer felt any desire for the more liberal diet general among his American compatriots. In January 1903 he spent thirty days in the physiological laboratory of Yale University, under the direct observation of Chittenden, who examined his excreta in order to ascertain the quantity of protein consumed. He was absolutely free to choose his articles of food and followed the varied, though very scanty, dietary to which he had for long accustomed himself.

The result of these researches was that Fletcher, on a constant body-weight of 71·940 kgrms., consumed an average of 41·25 grms.

of protein daily, *i.e.* less than half that which Voit considered the average, and without any compensation through a larger consumption of carbohydrates and fats.

In February, when Fletcher was on an extremely simple diet of cereals, milk, and sugar apportioned between two meals, food which he selected himself and found sufficient for his requirements and suited to his tastes, Chittenden ascertained for six consecutive days the quantity, chemical composition, and heat value of the food consumed, and also the amount of nitrogen discharged in the urine and faeces, and obtained the results shown in the following table:

Date.	Food taken.			Total.		Nitrogen discharged in—		Sum total in Grms.
	Protein in Grms.	Fat in Grms.	Carbo-hydrate in Grms.	Calories.	Nitrogen in Grms.	Urine in Grms.	Faeces in Grms.	
Feb. 2	31.3	25.4	125.4	900	5.02	5.27	0.18	5.45
" 3	46.8	40.2	266.2	1690	7.50	6.24	0.81	7.05
" 4	48.0	38.0	283.0	1747	7.70	5.53	0.81	6.34
" 5	50.6	40.5	269.0	1711	8.00	6.44	0.81	7.25
" 6	47.5	41.6	267.0	1737	7.49	6.83	0.81	7.64
" 7	46.8	39.8	307.3	1852	7.44	7.50	0.17	7.67
					43.15			41.40

These results give a total daily consumption of protein not exceeding an average of 45 grms., and also show that the quantity of fat and carbohydrate taken was so small that the energy value of the daily diet was little over 1600 calories.

The importance of these figures is very striking when compared with those of the *average diet* regarded as *normal* by Voit, which contains 118 grms. of protein, and gives a total energy value of 3000 calories.

The spare diet voluntarily chosen by Fletcher completely appeased his appetite, and was more than enough for nitrogenous equilibrium, and the maintenance of the whole organism, since the nitrogen lost during several days was less in quantity than that introduced with the food, and the total weight of the body remained the same during the whole experimental period.

In order to clear up the important question whether the alimentary regimen of Fletcher was sufficient for the performance of muscular work such as that of a workman or a soldier, Fletcher was asked to perform, in the gymnasium of Yale, under the direction of G. Anderson, the usual gymnastic exercises of a boat's crew, tiring exercises which cannot be performed by untrained persons without a painful sense of exhaustion lasting some time.

Although for some months Fletcher had taken no physical exercise beyond walks in the town, he succeeded, as Anderson tells us in his account, on the 4th, 5th, 6th, and 7th of February, in performing the athletic exercises with astonishing ease and with far less fatigue than is usually felt by persons of his age and condition.

Chittenden observes, with natural surprise, that in Fletcher's case a very scanty diet, of an energy value equivalent to half that ordinarily required, sufficed to supply the energy necessary for the performance of these exercises, without the organism being forced to draw on any of its reserves, without loss of weight, but rather with a slight retention of nitrogen, without causing exhaustion or any physical suffering whatsoever. Brought face to face with such results he asks: Have we a clear notion of the real requirements of the body with regard to daily nourishment? Do we really follow the best and most economical system for the maintenance of the body in perfect physiological condition? Should Fletcher's case be regarded as unique, attributable to exceptional slowness in the exchange of material, or can any individual of mature age live for any length of time on a diet of only about half what Voit calls normal, and do so not only without suffering from it, but on the contrary with resulting benefit to his health?

Having had the opportunity of studying in Succi a fast of thirty days, during which the daily loss of nitrogen gradually fell from 13.8 to 4 grms., the subject still remaining in good health and being capable of work, no one can be more inclined than myself to regard Fletcher's case as due to *exceptional slowness in the exchange of material and energy* brought about by organic conditions gradually acquired by several years of reduced diet.

Fletcher himself tells us that at the age of forty his state of health had become very unsatisfactory. "He was unable to engage in business, to frequent clubs, or to live the turbulent life of society. Although he had trained as an athlete in his youth, and had every comfort, he got into such a physical state that the insurance companies refused to insure his life. This unexpected disability, with its serious warning for the future, was such a blow to his hopes of long life, that it led him to make a great personal effort to find a way of salvation. . . . Having realised that the break-down of his machine was due to *over-eating*, he discovered how to cure himself with the help of an economical system of nutrition like that of Luigi Cornaro,¹ and how to obtain with a

¹ Luigi Cornaro, a Venetian nobleman, born 1467, died 1566, and therefore almost a centenarian, lived for many years on an incredibly scanty diet. At the age of eighty-three he wrote a treatise on "The Way to Live Long," followed by other works on the same subject, written at the ages of eighty-six, ninety-one, and ninety-five respectively. "They are written," says Addison, "in a spirit of gaiety, religion, and good sense, which proves that these qualities go hand in hand with temperance and sobriety."

small quantity of food much greater enjoyment than can be afforded by the best spread table."

It is easy to see that the functional disturbances which made the insurance companies refuse to guarantee Fletcher a long life were due to *obesity*. The cure, consisting as it did in a reduced amount of nourishment, was therefore extremely rational, and it was only natural that he should derive great benefit from it. It would be interesting to know what phenomena accompanied the abrupt transition from an abundant to an economical diet? Was a long and gradual training required? What was the curve of the loss in weight of his body? At the expense of what substances was this reduction effected? Was there at first a daily loss of nitrogen, gradually diminishing until a new state of equilibrium between the intake and output was attained?

We have no data which would enable us to answer these questions. The question of most importance is whether the balance of nitrogen became permanent and fairly elastic in Fletcher after several years of his alimentary regimen, or whether it remained variable, and led from time to time to slight losses of nitrogen. The experiments made by Chittenden on Fletcher did not last long enough to afford a conclusive solution of this problem. In order to reach such a definite conclusion fresh experiments on numerous individuals of varied types were necessary, such experiments to be carried on for a considerable length of time. The most recent studies of Chittenden, of which we shall next treat, had this end in view.

Fletcher, having read this chapter on human nutrition in the first edition of my book, wrote to me from London on 3rd July 1912, and the following extract from his letter seems to me to be worth reproducing:

"You may like to know that for twelve years after Sir Michael Forster had interested himself in the subject of my nutrition, I have succeeded in maintaining nitrogenous equilibrium for considerable periods on not more than 30 grms. of protein per day, derived from potatoes only, seasoned with butter and margarine, so as to supply the requisite calories, my weight remaining from 76-77 kilos.

"During these twelve years, from my fifty-first to my sixty-third year, I have led a very active life, having nothing to complain of but constipation, which I have, however, succeeded in getting rid of more and more. During the last two years I have had the opportunity of working with Dr. Hindhede of Copenhagen in order to determine the effects of the introduction of single articles of food (potatoes, bread, etc.) with the addition of nothing but fat, for periods of 40 and 150 days. The results of these special investigations, however, have not yet been published."

IV. The results of Chittenden's new researches upon the effects

of physiological economy in nutrition and the minimum of protein necessary for the adult man were published in London in 1905 in a long monograph of 478 pages, fully illustrated with diagrams and tables. They confirm the fundamental conclusion drawn from the experiments on Fletcher, that the quantity of protein habitually taken is far in excess of what is really strictly necessary for the adult man, and prove that this excess of nitrogenous substances is not only useless, but injurious to the animal economy.

These researches, which were carried out on a broad experimental basis, lasted several months. Determinations were made not only of the total quantity of nitrogen taken with the food and discharged in the urine and faeces, but also the uric acid, phosphoric acid, muscular and psychical activity, the relative number of erythrocytes in the blood, the daily variations in the weight of the body, and the general condition of the subjects of the experiments.

These persons belonged to three classes: the first group of *professional* men was composed of five professors and assistants of the University, Mendel and Chittenden himself being of the number; the second, of eight *students*, trained in gymnastic exercises and athletics; the third, of thirteen *soldiers* from various American States.

The main object of the researches was the reduction of the quantity of protein to a minimum without disturbance of nitrogenous equilibrium and the weight of the body; in other respects the subjects of the experiment had full liberty in the choice of food. The soldiers alone were not free to choose, but were limited to the prescribed rations, and were obliged to take a smaller quantity so as to reduce as far as possible the total quantity of protein consumed daily.

The total intake and output of nitrogen were determined daily by Kjeldahl's method, after the total amount of food, urine, and faeces had been weighed.

The greatest difficulty found by Chittenden in these researches was naturally the theoretical prejudice that at least 100 grms. of protein must be consumed daily in order to preserve nitrogenous equilibrium, and more especially the habit, which is deeply rooted in every one, of indulging in a diet excessively and quite needlessly rich in such substances. It will be readily understood that when men have been accustomed for generations to this lavish regimen, they naturally experience, when they begin to reduce it, a feeling of emptiness in the stomach and of general weakness which makes them think it necessary to return to their accustomed diet. It is therefore not surprising that about half the persons, students and soldiers, who had allowed themselves to be experimented on by Chittenden, could not stand the reduced diet prescribed in his plan of research. This fact does not, however,

detract from the scientific and practical value of the results obtained by Chittenden in his experiments on the other half, who had the courage and strength of will to hold out to the end of the test.

Chittenden has proved that after a few days the organism adapts itself and becomes accustomed to such a diet, if it be persevered with, and above all, if the change be effected gradually and not suddenly. Not only does the first feeling of emptiness and weakness disappear, but the general sense of comfort becomes more marked, the organism feels stronger and more inclined to work, and there is an increased sense of well-being. We observed and recorded something very similar with regard to the sensation of hunger in the case of Succi during the first days of his prolonged fast at Florence. It is, therefore, according to Chittenden, a mere prejudice to suppose that our physical and mental vigour and our power of resisting disease are increased by a plentiful diet of meat. Since purins, creatin, and uric acid, the intermediate products of the metabolism of protein, are pre-eminently toxic, it may, on the contrary, be argued that when an excessive quantity of meat is taken daily, a large quantity of these products circulates with the blood throughout the organism, with possible harmful results, specially to the nerve centres. We may add another important consideration: in order to digest all the protein food-stuffs, to transform and render innocuous all the intermediate products of their metabolism, and to eliminate, through the kidneys, all the final products, urea, uric acid, creatin, etc., we are forced to employ a great amount of glandular activity, partly to the detriment of the function of the higher tissues of animal life, such as the muscular and nervous.

"It is quite evident," concludes Chittenden, "from a study of the results obtained in the foregoing experiments that young, vigorous men of the type under observation, trained in athletics, accustomed to the doing of vigorous muscular work, can satisfy all the true physiological needs of their bodies and maintain their physical strength and vigour, as well as their capacity for mental work, with an amount of proteid food equal to one-half, or one-third, that ordinarily consumed by men of this stamp. As the results show, all these men reduced their rate of proteid metabolism, in such degree that the amount of nitrogen excreted daily during the period of the experiment averaged 8.8 grams, implying a metabolism of about 55 grams of proteid matter per day.

"In other words, these athletes were able to reduce their nitrogenous metabolism to as low a level as many of the men of the professional group and of the soldier group, and this with not only maintenance of health and strength, but with a decided increase in their muscular power.

"Metabolised nitrogen per kilo. of body-weight for all these

men, with one exception, during the experiment amounted to 0.108-0.134 gram per day, fully as low as was obtained with the members of the soldier detail on their prescribed diet. It is clear, therefore, that physiological economy in nutrition is as safe for men in athletics as for men not accustomed to vigorous exercise. There is obviously no physiological ground for the use of such quantity of proteid food, or of total nutrients, as the prevalent dietary standards call for.

"The athlete, as well as the less active man (physically), or the professional man, can meet all his ordinary requirements with an intake of proteid food far below the quantities generally consumed, and this without increasing in any measure the amount of non-nitrogenous food."

Chittenden's account of his results should be completed by mentioning the fact that during the long experimental period none of the individuals in the three groups lost at all in weight or complained of any feeling of discomfort, once the new equilibrium of nitrogen corresponding to the reduced diet was attained: on the contrary many of them noticed an improvement in their health, and preferred, therefore, to continue the diet poor in protein even after the experiment was at an end.

During a period of nine months, Chittenden, who weighed 57 kgrms., reduced the quantity of nitrogen discharged daily to 5.7 grms., and even during the last two months to 5.4 grms., which is equivalent to 0.1 and 0.094 gm. respectively of metabolised nitrogen per kgrm. of body-weight. His average diet consisted of 33.75 grms. of protein with the addition of a sufficient quantity of non-nitrogenous substances, fats and carbohydrates, to bring the total energy value to 2000 calories. Mendel, who weighed 70 kgrms., discharged daily an average 6.59 grms. of nitrogen, which is equivalent to 0.093 gm. of metabolised nitrogen per kgrm. His average daily diet was 40.8 grms. of protein and a total of 2500 calories.

If we compare these figures with those given by Voit, a simple calculation will show that Chittenden ought to have taken 85.5 and 96.6 grms. of protein daily, instead of the 33.75 actually consumed by him, without any harmful result, but rather with advantage to his health.

The sum total of the results obtained by Chittenden affords a strong argument for *economy in nutrition* and a serious objection to the generally accepted teaching of Voit. Chittenden's conclusions should give food for serious thought to doctors and hygienists, who frequently advise *over-nutrition* in almost all cases in which weak organisms have to be strengthened, without having the least suspicion of the harm which may be done by it, harm which they do not realise because it is only seen long after, *i.e.* in old age. One of the experimental results obtained by

Chittenden merits special attention on account of its practical importance: the fact that the quantity of uric acid eliminated in the urine increases almost in proportion to the quantity of protein consumed. He found a proportion varying from 1:14 and 1:20 between the uric acid and the total quantity of nitrogen in the urine.

It is desirable that Chittenden's researches should be repeated by doctors and hygienists on a large scale under similar and different conditions, taking into consideration climate, race, different trades and professions, the different states of development, pregnancy, lactation, convalescence, old age, and the various metabolic diseases.

The doctrine of *reduced or economical nutrition* has undoubtedly a great future before it, because it rests upon a number of undeniable facts which have been scientifically proved. If many are extremely unwilling to accept this doctrine, it is because it is in direct opposition to the inveterate habits which heredity has ingrained in us, and because it tends to forbid, or at all events limit, those pleasures which the prolonged activity of the sense of taste affords us. I consider that the chief use of the long mastication and salivation of each morsel of food recommended by Fletcher's disciples is to prolong the gustatory sensations as much as possible, so as to afford us the same amount of enjoyment with a small quantity of food as is obtained by the gluttons who hastily devour twice or three times as much.

I feel bound to protest in the name of experimental science against the immoderate and unfair opposition of certain doctors and hygienists to the results of Chittenden's researches. One of these critics writes as follows: "Under the cloak of great scientific accuracy he (Chittenden) tends to spread opinions which are repugnant to practical common sense and to sound biological intuition." What is the meaning of these dark utterances? Perhaps that Chittenden's researches merely *appear* to be strictly scientific, but were in reality carried out against the most accredited rules and methods? Are the results and numerical data published by him not genuine? In this case only—one which it would be absurd to take into consideration when we are dealing with researches conducted in association with others and in the presence of many persons able to check them—would the *common sense* and *sound intuition* be on the side of the critic; in the opposite case the critic has nothing on his side but *general opinion*, i.e. *traditional prejudice* and *false physiological intuition* which is its natural outcome. Let us briefly examine certain specific points. The critic states that Chittenden bases a large number of his proofs on the nitrogenous equilibrium attained, a phenomenon which is only of purely relative value. To this we reply that Chittenden in support of his doctrine of reduced

nutrition lays special stress not on the nitrogenous equilibrium attained, but on the *stability of this equilibrium for the space of nine months*. This is a very different matter and one of much greater practical and theoretical value. Our critic further objects that when Chittenden gave his subjects a larger quantity of protein than could be accounted for from the nitrogen of the urine, there was a retention of nitrogen which did not take place when the quantity of protein was smaller. I fail to see the force of this argument against Chittenden's doctrine. He does not deny that when a change is made from a reduced to a lavish diet there is a storage not only of non-nitrogenous reserve materials, glycogen and fats, but also of nitrogenous reserves, disseminated more or less throughout the tissues, he merely questions whether an excess of these reserves is necessary and beneficial or rather injurious to the physiological economy of an adult man engaged in muscular and mental work.

Our critic goes on to say that Chittenden's diet is not practical, since so many of the persons subjected to the experiment gave it up. We have already had occasion to note that this fact cannot detract from the value of the excellent results obtained in all those who had, like Chittenden himself, the courage to persevere with the reduced diet and to adopt it definitely as the physiological normal of their lives; it merely proves how deeply rooted our alimentary habits have become, how reluctant we are to correct them, and how weak is the will of many when it is a question of bearing the temporary discomforts attendant on the formation of new habits.

The good example of the wise, the proof of the good results obtained, the advice of well-known doctors and philanthropists will do much to spread the new teaching and induce people to adopt it.

Our critic adds that the effects of the reduced diet are too slow to be noticed experimentally; the remote effects of the reduced intake of protein escape Chittenden's observation. We may say in answer to this argument that if the immediate effects of the reduced diet are advantageous from every point of view, there is no reason for supposing the remote effects to be harmful. On the contrary, if we remember that with ordinary alimentary habits, we are obliged with advancing years and the growing infirmities of old age to moderate our diet gradually in proportion to the diminished activity of the digestive apparatus, it is only logical to suppose that the forces of the organism will remain longer unchanged when they have been already economised by a temperate diet.

Our critic distinguishes "*the absolute minimum balance of nitrogen compatible with human life from the practical minimum balance*" which allows the individual the full exercise of the

muscular and psychical faculties necessary for victory in the struggle for existence." The alimentary regimen tried for nine months by Chittenden and his fellow-workers—professional men, students, and soldiers—was sufficient to give a nitrogenous balance not of the first but of the second kind, as is obvious from what we have already said on the subject. Let our critic try to follow the example of these good people; he will lose part of his useless stored-up reserves and thick compact adipose layer which have increased the weight of his body and marred the Apollo-like lines of youth, but as compensation he will gain a greater degree of vigour in all his functions, including the sexual function to which he rightly attaches great social importance.

V. What we have said so far about the composition of human food applies to the ordinary mixed diet, in which the proteins, fats, and carbohydrates are derived from various articles of food whether they be of vegetable or animal origin. We must now deal briefly with the question whether a diet which is mainly vegetable or one which is mainly animal is more natural and hence more physiological and useful to man.

From the fact that the digestive organs of man resemble more closely those of carnivorous than herbivorous animals, some physiologists have argued that man was originally carnivorous and became omnivorous and even vegetarian owing to the varying conditions of the environment in which he was forced to live. This seems to me a wholly erroneous induction.

If we wish to form an idea of primitive man, whatever theory of descent we adopt, we should compare him not with the domestic animals, but the anthropoid apes living in a state of nature. Now it is well known that apes live upon an almost exclusively vegetarian diet; roots, seeds, and more especially fruits, form the basis of their nutrition, although they also indulge in eggs, small birds from the nest, and the larvae of insects. They are, in short, frugivorous and fruitivorous, with a tendency to become omnivorous. In all probability, therefore, man, who represents a higher stage of evolution, was originally omnivorous, but can readily become vegetarian or carnivorous, according to the latitude in which he is compelled to live and the flora and fauna found there.

The physiological proof that man more readily adapts himself to a vegetable than an animal diet is afforded by the fact that whereas it would be impossible for the civilised human races to live for any length of time on an *exclusively animal* diet on account of the inadequate digestive power of the alimentary canal, they can easily live, work, and prosper on a *purely vegetable* diet. The only exceptions to this rule are certain primitive tribes, such as the Bushmen, the Eskimos of Greenland, the Ostiaks, the peoples of the shores of the Red Sea, the shepherds

of the American Pampas, all of whom live on the spoils of hunting and fishing. Owing either to original characteristics, or ancestral habits which have become more and more ingrained with each generation, or to the conditions of the regions in which they are forced to live, the digestive apparatus of these primitive races has become so much stronger, at the cost of the functional development of the organs of psychical life, that it can tolerate a diet which is wholly or almost wholly animal.

Vegetarianism can be traced back to the most remote ages. Abstinence from animal food was originally a practice inspired by religious beliefs. The Hindus, who are disciples of Brahma and Buddha, believe in the transmigration of souls from animals to man and *vice versa*; hence they regard it as sacrilege to consume the flesh of animals, which they look upon as their "poor relations." The religion of the ancient Egyptians forbade the use of meat. Pythagoras introduced the Egyptian doctrines on food into Greece. Seneca the moralist, who adopted Pythagorean vegetarianism late in life, tells us (Epistol. 108) that in a year he found the new regimen not only easy but pleasant, and it seemed to him that his intellectual powers had developed greatly. Porphyrius, the neo-Platonist, who wrote the Biography of Pythagoras and a treatise "On Abstinence from Meat," maintained that a vegetable diet was not only better fitted to give perfect health, but also to sharpen the philosophical intelligence. In J. J. Rousseau's *Émile* we find an echo of this teaching, which is carried out more or less strictly by many owing to choice or necessity.

Vegetarians who are such from choice may be divided into two classes: those who, in addition to vegetable foods, make use of certain products of living animals, such as milk, cheese, butter, and eggs, and those who live on vegetable products only, seeds, fruit, green vegetables, potatoes, etc., and refuse all animal products whatsoever, including butter and other animal fats, for which they substitute vegetable oils.

Indian despatch bearers, who live on rice, traverse daily at least 20 leagues from one city to another, and can keep up this kind of life for weeks (I. Sinclair). Russian agricultural labourers who live on vegetables, garlic, brown bread and milk, work sixteen to eighteen hours a day, and are stronger than American sailors (Bremmer and Howland). Animal food is almost unknown to Norwegian peasants; and yet they will run beside travellers' carriages for 3 or 4 leagues. According to Lane and Catherwood, modern Egyptian workmen and boatmen are remarkable for their muscular strength, and yet from time immemorial they have lived almost entirely on melons, beans, lentils, onions, dates, and maize. The South American miners, who do not eat meat, can carry on their shoulders a weight of 200 pounds, going up vertical ladders 60-86 metres in height twelve times a day on an average (F. Head,

Playfair, Darwin). The workmen of northern Bavaria accomplish, according to Ranke, an enormous amount of work daily, yet they live almost entirely on 1100-1200 grms. of flour per day, cooked with 90 grms. of lard, without either eggs or cheese; on Sundays only is a little pork added. The sobriety of the Turkish soldier is proverbial; he lives on figs, rice, without any wine or meat, yet he is strong and very brave. The porters of Salonica and Constantinople who live in the same way are proverbial for their strength (A. Kingsford). A. Gautier relates that he has known extremely intelligent persons of both sexes, who, having become vegetarians for pseudo-scientific or hygienic reasons, found that the new diet suited them remarkably well, both as regards strength and well-being.

We may reply that these and similar observations, which are the result of experience, are not sufficiently accurate, since neither the quantity of protein taken daily nor the total energy-value and degree of utilisation of the vegetable diets in question were ascertained. It is, however, undeniable that they afford proofs that vegetarianism, whether absolute or nearly so, is a regimen which enables a man to live in good health and, moreover, to develop fully his muscular and nervous activity.

There is, however, no lack of scientific researches conducted in the laboratory on vegetarians, and of these we will give a brief summary.

Cramer (1882) observed for three days the metabolism of an official aged 62, who for eleven years had lived on a vegetable diet tempered with animal products. He took daily 71 to 75.8 grms. of protein, 47.7 to 74.7 fat, 349.9 to 642.2 carbohydrate, in the form of brown bread, milk, and eggs. With this diet nitrogenous equilibrium was maintained. Cramer, however, in accordance with Voit's doctrine, considered this diet insufficient and unsuitable, for he found that 21.13 per cent of the protein were discharged undigested in the faeces.

Voit (1889) experimented on a vegetarian paper-hanger aged 28, and weighing 57 kgrms., who had lived for three years on brown bread with oil and different fruits. The researches upon his exchange of material were divided into three periods, amounting to forty days in all. During these experimental periods his diet consisted of brown bread made of rye and wheat, apples, figs, oranges, dates, and olive oil. During the three periods the diet contained an average of 8.4 grms. of nitrogen = 54.2 grms. of protein, 22 of fat, 289 of sugar, 269 of starch (557 grms. of carbohydrates in all), 16 grms. of cellulose. This diet is equivalent to 0.15 gm. of nitrogen = 0.95 of protein, 0.38 of fat, and 9.77 of carbohydrate per kgrm. of body-weight, and about 47 calories, calculated according to Rubner's standard values.

The amounts lost in the faeces were higher than in the case of

an animal diet: 41 per cent albumen, 30 per cent fat, 3 per cent carbohydrate. The daily balance of nitrogen was on an average as follows :

	Period I.	Period II.	Period III.
Nitrogen of food . .	8·20	8·39	8·84
Nitrogen in the faeces .	3·34	2·79	4·45
Nitrogen absorbed . .	4·86	5·60	4·39
Nitrogen in urine . .	5·22	5·21	5·55
Balance . .	- 0·36	+ 0·39	- 1·16

As will be seen from these data, perfect nitrogenous equilibrium was not attained; for this reason Voit declared the diet to be insufficient and unsuitable, considering the large quantity of nitrogen which is unabsorbed and is wasted in the faeces. We may, however, fairly claim that perfect nitrogenous equilibrium would have been attained had the investigations lasted longer.

In order to ascertain whether the vegetarian who had for long been used to such a diet made better use of it than a person accustomed to a mixed diet rich in nitrogen, Voit experimented on the servant of the Institute, a man weighing 74 kgrms., for a period of three days, giving him the same diet as that to which the vegetarian was accustomed. The nitrogenous balance showed on an average a loss of nitrogen amounting to 4·95 grms. per day (on the third day 3·74 grms.). Although the experimental period was extremely short, the result obtained is important, showing, as it did, that the servant who was not used to a purely vegetable diet made the same use of it as the paper-hanger who had been accustomed to it for years.

At the same time as Voit's experiments a work on the nutrition of the Japanese was published in Germany by Kellner and Mori (1889). Mori himself, a strong young Japanese of 23 years of age, weighing 52 kgrms., was the subject of these investigations. The experiments on the exchange of material were divided into three series; during the first was tried a purely vegetable diet, like that general amongst the poorest class of agricultural labourers in the interior of Japan; during the second period a mixed diet with fish; during the third a mixed diet with meat and milk. The results obtained were not favourable to the vegetable diet, during which Mori lost nitrogen continually—an average of 1·16 grms. a day during the last three days. During the other two periods, on the contrary, he gained nitrogen. If, however, we take into account the fact that during the first period he took only an average of 70·80 grms. of protein, whereas the amount during the

second was 109.23 grms. and during the third 122.96 grms., it will readily be seen that the results are not comparable. On the other hand the period of vegetable nutrition was too short for nitrogenous equilibrium to be attained, seeing that Mori was not used to the vegetable diet of his peasant compatriots. The same objections may be made to the experiments carried out in Germany in 1889 by Kumagawa, another Japanese who was anxious to compare upon himself the effects of vegetable and mixed diets. Unlike Mori, in nine days of vegetarian diet, cooked in the Japanese fashion, he not only attained nitrogenous equilibrium, but succeeded in retaining 0.65 gm. a day, while only taking an average of 8.75 grms. daily (=55 of protein), *i.e.* a smaller quantity than that taken by Mori.

Of greater interest are the researches carried out at Tokyo by Taniguti (1892) on a vegetable diet based upon rice. The problem to be solved was whether it was desirable to continue the existing diet of the Japanese army, or to introduce certain changes into it. Taniguti ascertained the exchange of material of Japanese villagers by a series of experiments. We omit the results of the first series, because Liebig's meat extract was added to the rice diet as a relish or corrective. In the later series he tried a diet of rice and other vegetables chosen by the subject, the total energy-value varying from 2777 to 2790 calories.

The results obtained are shown in the following table:

	Period I. (ten days).	Period II. (ten days).	Period III. (ten days).	Period IV. (five days).
	Grms.	Grms.	Grms.	Grms.
Average intake of nitrogen .	9.63	10.52	10.35	10.41
Nitrogen lost in faeces .	1.94	2.13	1.89	2.39
Nitrogen absorbed . . .	7.69	8.39	8.46	8.02
Nitrogen discharged in urine	9.24	8.36	7.25	7.52
Balance	- 1.55	+ 0.03	+ 1.21	+ 0.50

In all the periods with the exception of the first, during which the subject of the experiment made the change from the habitual mixed diet to a purely vegetable one, a more or less important amount of nitrogen was retained. The fact should also be noted that the vegetable protein was readily digested and utilised, a fact which may be attributed to the wise choice of articles of food and the suitable way in which they were cooked.

Similar results were obtained by Rumpf and Schumm (1909) in their investigations on the exchange of material in a vegetarian of eighteen years of age, weighing 65.5 kgrms., who lived on brown bread, rice, nuts, dates, and sugar. The experiments lasted

eight days, during which his daily allowance was 73·88 grms. of protein, 28·64 of fat, and 698·21 of carbohydrates, with a total energy-value of 3432 calories, reckoned according to Rubner's standard figures. The nitrogenous exchange on each of the eight days averaged as follows :

Nitrogen introduced in the food	11·82	grms.
Nitrogen lost in the faeces	4·01	"
<hr/>		
Nitrogen absorbed	7·81	"
Nitrogen discharged in the urine	6·91	"
<hr/>		
Balance	+ 0·90	"

In this case the quantity of nitrogen lost in the faeces was very large, 33·93 per cent; this was owing to the food being badly selected and cooked. Nevertheless there was a remarkable accumulation not only of protein, but also of non-nitrogenous substances, fats and carbohydrates, for after the eight days of experiment the weight of the youth had increased by 1700 grms. The diet was therefore more than sufficient as far as protein was concerned, and undoubtedly excessive as regards carbohydrates.

Albu in 1901 experimented for six days on a medical student—a woman aged 42, weighing 37·5 kgrms., who for six years had lived on a very sparse vegetable diet. The articles of food taken by her during the six days' experiment were: brown bread, apples, prunes, grapes, nuts, dates, and salad; the daily quantity of protein being 34·12 grms. (=5·46 grms. of nitrogen), fat, 36·44 grms., and about 225 grms. of carbohydrates, with a total heat-value of 1400 calories, about 37 calories per kilo. body-weight. Although, owing to the indigestibility of the nuts, 36·79 per cent of the nitrogen was lost in the faeces, not only was nitrogenous equilibrium attained, but there was an average daily retention of 0·37 gm.

Hauer (1903) investigated the metabolism of a gentleman 36 years of age, weighing 64·93 kgrms., who for two years had lived on a diet of raw vegetables during the summer and cooked vegetables during the winter. The researches lasted six days, from the 7th to the 12th of July 1902, during which his food consisted of bread, cherries, strawberries, figs, dates, almonds, nuts, and a kind of butter made of nuts. He was free to choose from the above articles both the quantity and kind of food he desired. The quantity taken varied considerably in the six days of the experiment; it averaged per day 10·95 grms. of nitrogen, 112 of fat, with a total of about 2789 calories, which is equivalent to 0·16 gm. of nitrogen, 1·7 of fat, and 42·9 calories per kilo. body-weight. Nitrogenous equilibrium was obtained, although 38 per cent of the nitrogen and 22 per cent of the fat were wasted in the faeces. In 1904 Caspari collaborated with Glaessner in studying

the metabolism of a vegetarian married couple, an engineer aged 49 and his wife aged 48 years. From 1883 to 1891 the engineer lived on cooked vegetables, with milk, eggs, cheese, and butter. From 1891 to 1903 he adopted a strictly vegetable diet, to which he adhered during the experiments made by Caspari. His wife had lived on a mixed diet until the end of 1899, when she took to the same strictly vegetarian diet as her husband, and adhered to it during the investigations.

These investigations lasted five days, from the 5th to the 9th of February 1902, during which the engineer took active muscular exercise, and performed certain gymnastics. His food consisted of barley-water, sugar, dates, nuts, olives, peeled and cooked potatoes. His wife's diet was the same except that she did not take sugar, but cocoa and cooked carrots instead. The quantity of food taken varied considerably during the five days of the experiment. The total quantity consumed in five days by the engineer was 39.15 grms. of nitrogen, and 1099.1 fat; in the case of his wife, 26.64 of nitrogen, and 495 of fat.

The total number of calories, ascertained directly by combustion, was 22796 for the engineer, 13573 for his wife.

The daily averages were respectively :

Nitrogen 7.83 grms.	Fat 219.8 grms.	Calories 4559.
" 5.33 "	" 99 "	" 2715.

The averages per day, and per kilo. body-weight, were :

Nitrogen 0.114 gm.	Calories 66.
" 0.092 "	" 47.

Of the food taken the amounts utilised were respectively :

Nitrogen 73.79 per cent.	Fat 88.49 per cent.	Calories 91.11 per cent.
" 75.79 "	" 89.92 "	" 92.93 "

The engineer during the five days retained 5.20 grms. of nitrogen = 156 grms. of flesh; his wife 2.45 grms. of nitrogen = 73.5 of flesh. He gained 800 grms. in weight; his wife 900 grms.

Caspari, after summing up all the scientific researches which have been made into this subject, concludes that they undoubtedly teach us that a purely vegetable diet, even a raw one, "is capable of keeping a young and vigorous organism at the highest level of bodily and mental activity and capacity for work."

A searching and accurate examination of the drawbacks and advantages of vegetarianism as compared with those of a mixed diet will readily give the following results :

(a) The sum total of empirical observations and scientific investigations of a purely vegetable diet afford manifest proof that vegetable foods in general are less fully utilised than animal foods; a smaller quantity of the nutritive substances contained in them

is digested and absorbed by the intestines. The quantity of nitrogen lost in the faeces is considerably larger than is the case with a mixed diet. We have seen that vegetarianism does not increase the capacity for digesting vegetable foods, or decrease the faeces or the percentage of nitrogen lost in them. It is obvious that this is due to the fact that the protein of foods consisting of vegetable tissue is enclosed in membranes of cellulose which the digestive juices of man are unable to attack.

This drawback to a vegetable diet can, however, to a great extent be obviated by a wiser choice of articles of food and more especially by preparing them in the form of broth (the *pulmentum* of the ancient Romans). Taniguti's researches at Tokyo afford sufficient proof of this statement.

(b) The most serious objection to vegetarianism is the *relative poverty* in protein of the main articles of vegetable food, which makes it necessary to take an *excessive quantity of food* in order to introduce the normal minimum of protein necessary for the maintenance of nitrogenous equilibrium. If this minimum quantity really exceeded an average of 100 grms., as was asserted by Voit, vegetarianism would stand condemned. The weight of this objection is, however, very much lessened by Chittenden's proof that a daily quantity of protein amounting to less than half that laid down by Voit is sufficient not only to support life, but also to enable the organism to flourish, and to perform both muscular and mental work. If to a diet consisting only of maize, potatoes, chestnuts, and green vegetables, such as Albertoni and Rossi found to be the staple food of the poorest of the peasantry in the Abruzzi, we add a fair proportion of vegetables such as beans, lentils, and peas, we have a diet which is sufficient without overloading the digestive organs with an excessive amount of food.

(c) Another objection which may be made to a vegetable diet is the comparative insipidity of vegetable foods; they do not sufficiently stimulate the taste, with the result that the digestive juices are not secreted in large enough quantities and the digestion becomes defective. The objection may, however, easily be met by the addition of suitable flavourings made of aromatic substances. Even our poorest peasants use a large quantity of pepper and pepper-corns. The Japanese, who live mainly on rice, are extremely skilful in the addition of different flavourings for the preparation of most appetising dishes.

We will now consider the advantages claimed by the advocates of vegetarianism for such a diet compared with a mixed diet.

(a) One of the advantages vaunted by vegetarians is that a vegetable diet corrects the tendency to arthritic, gouty, and rheumatic diathesis. Some maintain that the substances which form uric acid are absent in vegetable proteins. There is, however, nothing to prove this theory at the present stage of our scientific knowledge.

It is probably an arbitrary interpretation of empirical facts, which may be accounted for more simply as the results of temperance. The formation of uric acid is lessened, not by the substitution of vegetable for animal proteins, but rather by the smaller quantity taken daily, as is clearly proved by Chittenden's experiments. The question is, however, sufficiently interesting to form the subject of further investigations into the physiological properties of the different groups into which animal and vegetable proteins may be divided.

(b) Another argument in favour of vegetarianism is that vegetable foods, being extremely rich in dynamogenic substances (carbohydrates), are specially fitted to sustain human muscular labour. There is some truth in the statement. Caspari discusses in detail the case studied by him in relation to a long distance walking match from Dresden to Berlin (202 kilometres), which was won by a young vegetarian, who accomplished the distance in 26 hours and 58 minutes. But if this and other undeniable facts, such as the great powers of resistance shown by the Japanese army during the Russo-Japanese War, point to the desirability of a predominantly starchy diet, they contain nothing to prove the theory that a purely vegetable diet is preferable to a mixed one.

(c) Another argument in favour of vegetarianism is the economic factor, which must not be underrated from the social point of view; a vegetable diet sufficient to support active life costs considerably less. A large part, however, of the alleged saving disappears if we take into consideration the fact that intelligent selection, careful cooking, and the correct addition of flavouring to render such a diet appetising and stimulating to the nervous system are essential, if we are to avoid the drawbacks of a purely vegetable diet. On the other hand, if we add to the vegetable diet those animal products which are within the reach of all, such as milk, cheese, lard, and eggs, we obtain a diet only slightly more expensive, and one which avoids in a very simple way all the drawbacks of strict vegetarianism. Such a diet forms the fare of fast days among Catholic, Mahommedan, and Buddhist religious orders, and yields, as Gautier remarks, "the advantages of both the ordinary mixed diet and strict vegetarianism." This is the conclusion to which I myself have come on the subject of vegetarianism.

VI. Having considered at length the question of the nutrition best suited to the adult leading a normal active life, it only remains to add some remarks with regard to the variations in the diet determined by *sex*, the *anaplastic phase or stage of growth*, and the *cataplastic stage or old age*.

It is generally admitted that a woman requires considerably less food than a man, and this difference is supposed to be due to the fact that her body weighs 30-40 per cent less than his.

This explanation is, however, inadequate, since, as we have seen in the preceding chapter, the processes of oxidation are generally more intense in small than in large individuals, whether men or animals, because, the surface of their bodies being larger in proportion to their weight, they lose a relatively larger quantity of heat, and must, therefore, introduce a larger quantity of heat with their food. Moreover, certain observations of Camerer and Schmidt show that girls and women need a smaller quantity of food than boys and men *even when their weight is the same*. This fact is due to the less active muscular life led by women as compared with men, the smaller development of the muscles and the greater thickness of the subcutaneous adipose layer, which contributes to the charm and grace of the female figure, and finally the less intense metabolism of the women.

A gradual increase in the regular diet is, however, observed in women both during pregnancy and nursing, because during these two functions peculiar to the sex the foetus and the new-born child are nourished at the expense of the blood and milk of the mother.

The mother's milk is the best and most natural nourishment for the infant when her state of health, both as regards her general condition and the quantity and quality of the mammary secretion, permit suckling. When this is not possible and a good wet-nurse cannot be obtained, the child should be given ass's milk, which closely resembles that of woman, or humanised cow's milk, *i.e.* a mixture consisting of $\frac{1}{3}$ of a watery solution containing 14·3 per cent lactose, and $\frac{2}{3}$ of fresh cow's milk. The percentage compositions of human milk, cow's milk, and the above-mentioned mixture are as follows:

	Protein.	Fat.	Lactose.	Salts.	Water.
Woman's milk . . .	2·01	3·74	6·37	0·30	87·58
Cow's milk . . .	3·35	3·55	4·88	0·70	87·52
Humanised milk . .	2·23	2·37	8·02	0·48	86·91

From these data we see that humanised milk as compared with woman's milk contains a little more protein, but 1·37 per cent less fat, which is made up by 1·65 per cent more lactose.

König's statistics of infant mortality according to the different forms of nutrition are extremely striking. Out of 1000 children after 1 year

610 of those nursed by their mothers were flourishing, and	82 were dead.
260 of those who had wet-nurses	180 "
90 brought up by hand	510 "

The results of the numerous researches upon the increasing intake of food by children during the first year of life, which were carried out by Camerer (1894), Rubner and Heubner (1898), Pröscher (1898), and Joannessen and Wang (1898), are shown in the following table drawn up by König:

Age.	Weight of Body in Grms.	Daily quantity of Milk in Grms.	Protein in Grms.	Fat in Grms.	Lactose in Grms.	Calories.		Cal. per sq. metre of surface of body.		Cal. per kgr. of weight of body.	
						Introduced.	Utilised.	Introduced.	Utilised.	Introduced.	Utilised.
1 day .	3000	20	0·4	0·7	1·2	13·2	12·9	530	518	4·4	4·3
1 week	3020	350	7·0	13·1	22·3	244·8	238·6	979	954	81	79
2 weeks	3040	400	8·0	14·9	25·5	279·2	272·1	1108	1080	91	89
3 "	3250	480	9·6	17·9	30·6	335·3	326·7	1290	1250	103	100
4 "	3450	550	11·1	20·6	35·0	385·7	375·4	1430	1390	111	108
5 "	3300	600	12·1	22·4	38·2	419·6	408·9	1440	1407	110	107
10 "	4850	800	16·1	29·9	50·9	559·5	545·2	1645	1600	115	112
20 "	6000	900	18·1	33·7	57·3	630·1	614·0	1600	1555	105	102
30 "	7300	1000	20·1	37·4	63·7	699·8	681·9	1555	1515	96	93
40 weeks	8880	Cow's milk. 1300	44·1	45·5	63·4	889·9	855·1	1745	1680	101	98
52 "	9850	1500	50·8	52·5	73·2	1026·5	984·7	1866	1790	104	101

The average increase in weight of a child during the first year of life is, as will readily be seen from the above table, 18 grms. per day, varying in different weeks from 4 to 30 grms. It may, therefore, be considered that during the first year of life the child needs for its exchange of material per kgrm. of its body-weight a daily average of 140-150 grms. of mother's milk, containing 2·8 grms. of protein, 9·5 of carbohydrate, and 5·5 of fat, with a total energy-value of 102 calories. Of course these average figures may vary considerably, according to individuality, sex, season of the year, and other factors less easily determined.

The great intensity of the exchange of material in the child as compared with that of the adult is especially noteworthy. The amount of protein, fat, and carbohydrate per kilo. body-weight taken by the child at the breast is greater, not only than that of the adult living on Chittenden's *reduced diet*, but also of those accustomed to the *generous diet* of Voit, Atwater, and Tigerstedt. Whereas the child at the breast utilises from 79 to 112 calories per kgrm. of its weight, adult Europeans and Americans only utilise from 27 to 61, as will be seen by reference to the tables on pages 93-94. This difference is due not only to the fact that the child loses to the environment as much greater an amount of heat as the surface of its body, in proportion to its weight, is greater than in the adult, but also to the fact that it retains on an average for the development of its body 18 grms. a day of the plastic and respiratory food substances introduced in the milk.

The bodily growth of the child increases most rapidly during the period from 1 to 15 years of age. It is during this period, also, that the largest amount of nourishment is required in proportion to the weight. W. Camerer (1904) carried out upon his children a complete series of investigations into the metabolism from the age of 2 to 24 years. The diet consisted of milk, bread, rice soup, roast meat, and eggs.

The total results obtained are shown in average figures in the following table :

Age in Years.	Body-Weight in Kilos.	Daily Intake.			Per 1 Kilo. Body-weight.			Total Energy-Value.	
		Protein in Grms.	Fat in Grms.	Carbo-hydrate in Grms.	Protein in Grms.	Fat in Grms.	Carbo-hydrate in Grms.	Calories per 1 sq. metre of body-surface.	Calories per 1 kgm. of body-weight.
Girls.									
1-2	12	44	38	115	3·7	3·2	9·6	1460	80
4-6	16	48	30	180	3·0	1·9	11·2	1450	70
8-10	22	60	30	220	2·7	1·4	10·0	1390	60
11-14	32	68	44	270	2·1	1·4	8·8	1330	51
15-16	41	60	35	219	1·5	0·9	5·3	930	53
21-24	44	67	71	242	1·5	1·6	5·5	1150	40
Boys.									
5-6	18	64	46	197	3·6	2·8	10·9	1680	77
7-10	24	67	32	251	2·8	1·3	10·5	1440	61
11-14	34	86	34	262	2·5	1·0	7·7	1250	47
15-16	53	102	73	287	1·9	1·4	5·4	1220	40
17-18	59	100	83	302	1·7	1·4	5·1	1200	38

We will confine ourselves to pointing out the most important conclusions to be drawn from these results :

(a) The daily intake of food in proportion to the weight of the body diminishes steadily with increasing years, until it assumes a permanent value when the girl weighs 40-45 kgrms. and the boy 50-60 kgrms.

(b) The daily intake of food is greater in boys than in girls at every age investigated, and the exchange of material is more intense in boys than in girls.

(c) The energy-value of the daily diet per unit of body-surface or weight steadily diminishes with age in both sexes. More or less important deviations are noticeable at the beginning of menstruation and puberty respectively.

The successive investigations of Hasse, Uffelmann, and others led to conclusions agreeing in essentials with those of Camerer.

Whilst the amount of nourishment required gradually increases during the anaplastic stage, the reverse holds good for the cataplastic stage. As virility gradually merges into old age, the

sharpness of the senses and the metabolic activity of the organs gradually diminish. In consequence of the lessened digestive power of the alimentary canal old people are forced to reduce the quantity of food taken and to choose the most easily digested and best-cooked kinds of nourishment. König advises the aged not only to add the necessary condiments and nerve stimulants to their food, but also to take wine, and quotes the old saying, "Wine is the milk of the aged." I am so convinced that this is extremely bad advice, inspired by physiological and hygienic notions which have been discarded and are opposed to daily observation, that I should feel that I was neglecting a duty if I did not say frankly that my views are diametrically opposed to this theory. Eggs, milk, farinaceous foods, such as maccaroni, the time-honoured and wholesome food of the Italian people, white meats of fish and poultry, tender vegetables, ripe fruit : such are the articles of diet amongst which the aged may choose the sparse diet necessary to prolong their lives. Every sensible old man, who has inherited a sound constitution, may and should hope to preserve, if not his muscular strength, and the vividness of his imagination, at all events his most essential mental functions, and his critical powers, and to live to be a hundred. He can do much to attain this end not only by the methodical, calm, and moderate exercise of all his functions, but also by temperance and a suitable choice of diet, a choice guided rather by personal experience of his digestive powers than by his tastes.

Even the advocates of Voit's generous diet admit that the food of old people should be much less abundant than that of the middle-aged. Tigerstedt considers that the diet of all those, who from either old age or the special state of their health are no longer able to perform muscular work, should be composed of 67 grms. of protein, 28 fat, and 377 carbohydrate, with a total energy-value of 2064 calories taken, and 1858 calories utilised.

As a result of an investigation of the metabolism of three persons no longer able to work, who were allowed complete liberty in the choice of their food, both as regards quantity and quality, Tigerstedt and Sonden found 61-79 grms. of protein consumed (= 9.8-12.6 grms. of nitrogen in the urine), 73-77 grms. of fat, and 195-205 grms. of carbohydrate, with a total of 1815-1823 calories utilised.

The researches carried out by Ekholm into the exchange of material of ten old men of from 68 to 81 years of age gave the following results expressed in outside figures: 48-96 grms. of protein (= 7.8-15.4 grms. of nitrogen in the urine), 0-50 grms. of fat, 216-383 grms. of carbohydrate, totals of = 1398-2114 calories, or an average of 1806 calories utilised.

Scientific researches into the metabolism of old people, who have long been accustomed either to vegetarianism or Fletcher's

reduced diet, are at present lacking; but if we consider the average figures of the diet of old people given by Tigerstedt, Sonden, and Ekholm, we find the intake of protein and the output of nitrogen a great deal higher than those resulting from the experiments carried out upon themselves by Chittenden and Mendel, while the number of calories utilised is lower. From this it will be obvious that, in order to prolong life to its utmost limits, old people require a diet containing less protein and proportionately more fat and carbohydrate than that tried by these authors.

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CHAPTER IV

THE GENERATIVE SYSTEM OF THE MALE

SUMMARY.—1. Structure of the *testicle*; formation of the *spermatoblasts* and *spermatozoa*; characters and chemical composition of the *sperm*; physiological properties of the spermatozoa. 2. Structures and functions of the *epididymis*, *vas deferens*, and *vesiculae seminales*. 3. Structures and functions of the *prostate* and *Cowper's glands*. 4. Structure of the *corpora cavernosa of the penis*, *urethra*, and *glans*, theory of the mechanism of erection. 5. Expulsive muscular forces on which the *ejaculation of the seminal fluid* depends. 6. The nervous centres and nerves concerned in erection and ejaculation. 7. The influence of the activity of the male genital apparatus on the organism as a whole, deduced particularly from the effects of castration. Bibliography.

THE functions which are co-ordinated in the reproductive act are those by which the individual provides for the maintenance of the species. The individual perishes, the species endures: thus arises the necessity that the individual should have the capacity of reproducing himself, transmitting to other individuals his own type for the conservation of the species.

In many animals, specially in the immense class of insects, the last great act of individual life is that by which the species is maintained: the individual dies shortly after having reproduced itself. Love, the creator, and Death, the destroyer, often fraternise in nature, as in the famous poem of Leopard.

The individual is the organ of the species, and as such is provided with special apparatus, of which the most essential parts, the organs producing the reproductive cells, are constructed on the glandular type. For this reason some physiologists treat *spermatogenesis* and *ovulation* as a special section of the common secretory functions. To appreciate the fallacy of this classification it is sufficient to reflect on the profound difference in the physiological significance of the functions of the common glands and the testicle and ovary. The first serve to elaborate and separate special anabolic and catabolic products which effect haemopoiesis and haemolysis, and, in general, serve to establish and regulate the physiological correlations of the different organs; the second, on the other hand, serve for the formation and separation of elementary sexual organisms (*spermatozoa and ova*) which, con-

joining, form the germ (*the fertilised ovum*) in which are contained the potentialities of the entire organism to be born, the determinants of the entire ulterior development, and all the rudiments of the hereditary characters of the two generations.

Towards the constitution of the germ the whole organisms of the parents co-operate in a process ever mysterious, and it is on this account that generation or reproduction, although it is carried out by means of special sexual apparatus, can and logically must be considered—as a most important integral part—in the *physiology of the organism as a whole*.

Faithful to our programme of keeping within the limits of the physiology of man, we must refer the reader to treatises on botany and zoology for the study of the various forms and modes of *agamie* and *monosexual generation* (*division, gemmation, unfertilised ova or parthenogenesis*) and confine ourselves exclusively to the study of *bisexual generation* (*fertilisation of the ovum of the female by means of the spermatozoon of the male*) which is observed exclusively in the higher animals and man.

I. During embryonic development both the male and the female sexual apparatus appear as generative layers in which no sexual difference can be recognised. Only at a given period of development are differences evolved which indicate masculine or feminine characters. The different parts of the embryonic genital apparatus then acquire a special form, structure, and relations in the two sexes: some develop and become of great importance, others atrophy or remain rudimentary. It is, however, always possible with the data furnished by embryology to reduce to a common fundamental type the sexual apparatus of the two sexes, and to discover the homologies between male and female parts.

The *testicle* is the homologue of the *ovary*, the *vas deferens* of the *oviduct*; the *vagina* and *uterus* of the female are homologous to the *utriculus prostaticus*, a quite rudimentary organ called by Weber the *male uterus*; the *clitoris* corresponds to the *penis*; the *labia majora* to the *scrotum*. These homologies explain the so-called cases of *hermaphroditism* in mammals and man described by the ancients. It is not a question of true but only of apparent hermaphroditism, due to some parts reaching an exaggerated development, while others are incomplete, and thus resemble the parts of the opposite sex.

The essential organs of the male genital apparatus are the *testicles*, because in them are formed the sexual cells of the male which are named *spermatozoa* (*zoosperms, spermides, or spermatic filaments*).

In section (Figs. 17, 18) the testis is seen to be formed of a parenchyma surrounded by a fibrous capsule, the *tunica albuginea*, which at the posterior border of the organ becomes thickened to form the *mediastinum testis*, or *corpus Highmori*. From this

radiate fanwise many thin fibrous laminae or septa which are continued to and reunite at the internal face of the tunica albuginea so as to form pyramidal spaces containing the soft, yellowish-brown substance of the parenchyma, which in this way becomes divided into a great number of lobules (250-300 according to Sappey).

The parenchyma of the lobules is formed of a mass of fine, *convoluted seminiferous tubules* bound together by an interstitial substance. At the apex of each lobule the tubules become

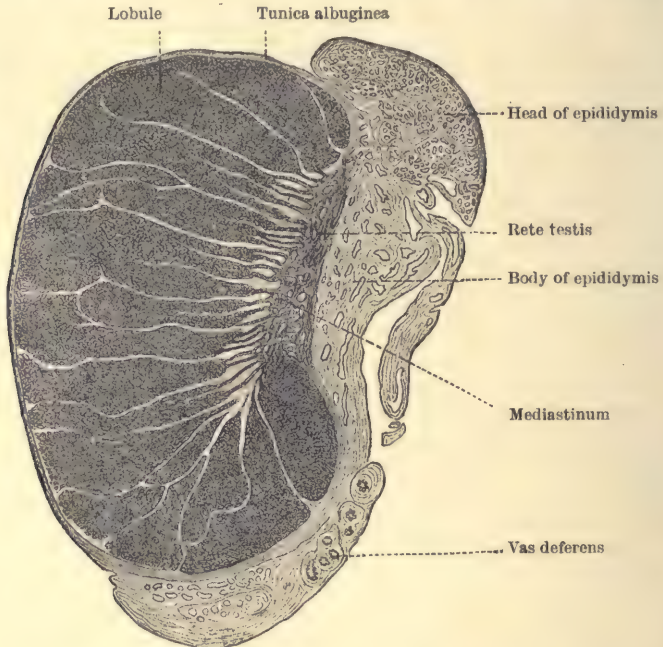


FIG. 17.—Sagittal section of the testicle and epididymis. (Böhm and Davidoff.)

straight, penetrate the mediastinum, and unite, forming the *rete testis*, from which emerge the *efferent ducts* which pass into the head of the *epididymis*, and after a complicated course open into a single canal called the *vas deferens* (Fig. 19). The *convoluted seminiferous tubules* have a diameter of 0.15-0.18 mm. (Sappey), and to the number of 3 or 4 or even 5 or 6 are found in each lobule. With suitable methods of maceration and separation they can be isolated and unfolded in order to estimate their length, which proves to be 30-35 cm. in the smaller lobules, and 120-175 in the larger. The different tubules of each lobe unite in one *straight tubule* before forming the *rete testis*.

Each *convoluted tubule* is covered by a delicate homogeneous

membrane composed of closely interwoven elastic fibres; it contains internally a stratified epithelium, and externally has a network of capillary vessels. The stratified epithelium consists of cells of two different kinds—the *seminal cells* and the *cells of Sertoli*. The first are disposed in different strata which correspond to different generations of these elements; the second occupy all the surface of the epithelium and are intercalated between groups of seminal cells. When the testicle, owing to the early age of the subject, is not yet in sexual activity, the cells of Sertoli are numerous, and have the appearance of a simple cylindrical epithelium; on the other hand, when sexual activity begins, there is observed a multiplication of the sexual cells which are interposed among the cells of Sertoli,

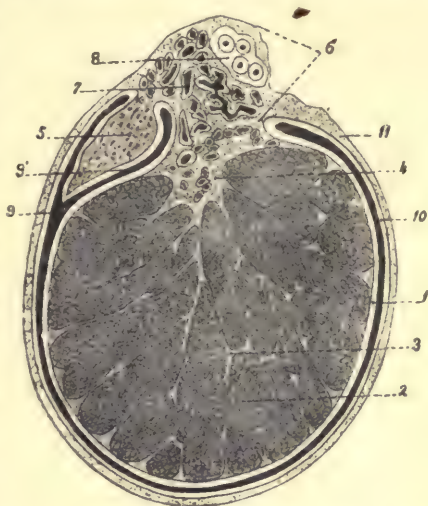


FIG. 18.—Transverse section through middle of right testicle with epididymis and spermatic cord. 1, tunica albuginea; 2, parenchyma of testicle (lobules); 3, septa of testicle; 4, mediastinum; 5, body of epididymis; 6, spermatic cord; 7, veins of the cord; 8, vas deferens; 9, cavity of tunica vaginalis; 9', interior of epididymis; 10, tunica vaginalis propria (parietal lamina); 11, tunica vaginalis communis.



FIG. 19.—Diagram of a sagittal section to show the structure of the testicle and epididymis. 1, tunica albuginea; 2, septa; 3, mediastinum; 4, lobule; 5, convoluted seminiferous tubules; 6, straight tubules; 7, rete testis; 8, efferent ductules; 9, conus vasculosus; 10, 10, appendices of the rete; 11, duct of the epididymis; 12, vas aberrans inferior; 13, vas deferens; 14, paradidymis.

and in the successive stages of their evolution transform themselves into *spermatogonia*, *spermatocytes*, and *spermatids*, the last of which change into *spermatozoa*. These different phases of metamorphosis of the sexual cells are represented in their various stages in Fig. 20.

During their transformation into spermatozoa, the spermatids contract special relations with the cells of Sertoli growing to

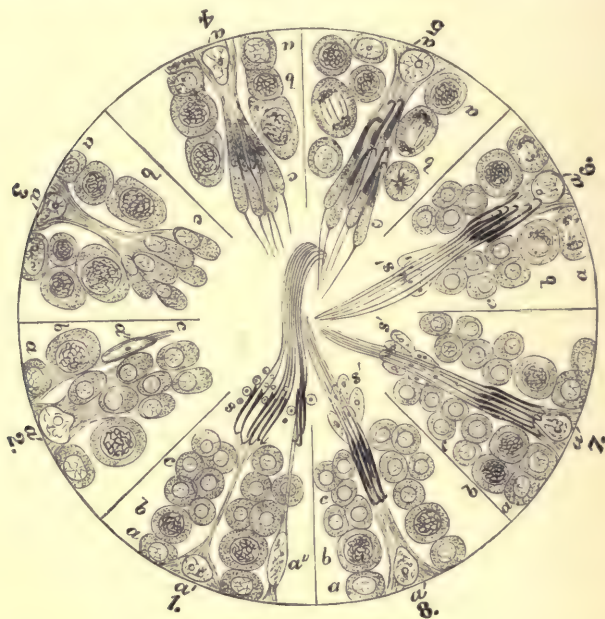


FIG. 20.—Diagram of a section of a convoluted seminiferous tubule of a mammal to show the evolution of seminal cells. The tubule is supposed to be divided into eight sectors, in each of which are represented successive stages of the development of the spermatozoa (according to E. A. Schäfer). *a' a''*, cells of Sertoli; *a*, spermatogonia; *b*, spermatocytes; *c*, spermatids; *s*, parts of the body of the spermatids which are dissolved when the spermatozoa are mature; *s*, group of spermatozoa with granules in between derived from the destruction of one part of the body of the spermatids. Some sectors, specially 2, 3, 4, 5, give a clear idea of a spermatoblast, formed from a cell of Sertoli, *a'*, and of a group of spermatids, *c*, transforming themselves into spermatozoa. In the sectors 6, 7, 8, 1 are seen groups of spermatozoa at a stage of development far more advanced, with the tails directed towards the free part of the tubule, flanked by young spermatids of the subsequent generation.

their distal parts to constitute the so-called *spermatoblast*. It is a *cellular copulation* (analogous to that observed in many invertebrate animals) which influences the nutrition, and the transformation of the spermatids into spermatozoa. When this has occurred, the *spermatozoa* detach themselves from the spermatoblast and become free in the lumen of the tubule.

The spermatozoa of man are filaments 50-55 μ long, in which may be distinguished a head and a tail formed of different segments

(Fig. 21). In a surface view, the head has an oval form, but the anterior half is much flattened, and when seen in profile shows a fine pyriform extremity. The anterior part of the head is enclosed in a membrane (*galea capitis*) which terminates in a transverse line between the anterior two thirds and posterior third of the head. A very short segment of transparent substance, the *neck*, forms a continuation to the head. In the neck are observed two granules (*centrosomes*) which, as we shall see, have a most important function in fertilisation. The neck is continued in an *intermediate segment* in the form of a small rod which is followed by the *principal part of the tail* and the *terminal part*, which is very fine.

The spermatozoon (first discovered with the microscope by Hammer, a pupil of Leeuwenhoek, in the human semen in 1677) has the morphological significance of a cell; the head represents the *nucleus* of the seminal cell, the neck and intermediate segment represent the *protoplasm* (fibrillary) containing the *centrosomes* and the caudal filament the *protoplasm* (fibrillary) without *centrosomes*.

The quantity of semen which is emitted at each ejaculation varies from a minimum of 0.85 c.c. to a maximum of 5.6 c.c. On an average one may assume a quantity of 3 c.c. (Mantegazza, Lode). In successive ejaculations within the space of twelve hours, the quantity of seminal fluid progressively diminishes from the maximum to the minimum; but in the interval of only a day between one ejaculation and another, the quantity of the secretion in the healthy adult man returns to the normal average. The specific gravity of the semen varies, according to Lode, from 1027 to 1046; the average is 1036. In the state in which it is emitted it appears as a viscous liquid, tenacious, whitish, with an alkaline reaction, and a specific odour due to the prostatic secretion with which it is mixed. In the first

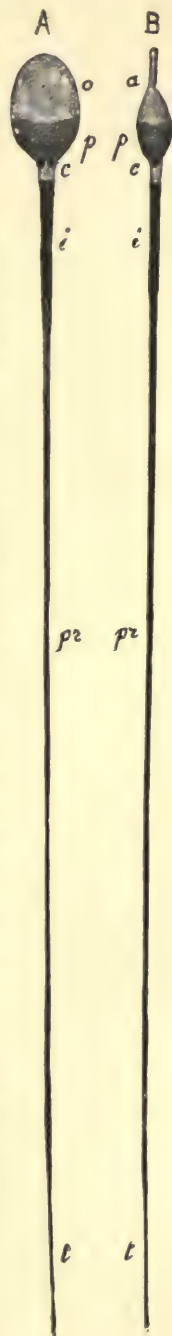


FIG. 21.—A typical human spermatozoon, extended in rectilinear position. A, with the head seen in superficies; B, with the head seen in profile. (Retzius, 1902.) a, anterior part of the head and cowl (in A is seen also a little dark point); p, posterior part of the head; c, neck with centrosomes; i, intermediate piece, part connecting with tail; pr, principal part of the tail; t, terminal part of the tail.

minutes after emission it takes a gelatinous form, but a few minutes later it becomes more fluid and remains less viscous. It contains 90 per cent of water and 10 per cent of solid substances. Of the latter, the greatest part is represented by mucin and the remainder by salts, proteins, and extractives. The spermatozoa contain besides proteins, nuclein, nucleic acid, nuclein bases, cerebrosin (akin to cerebrin), also cholesterol, lecithin, and traces of fats and salts.

The chemical composition of salmon sperm, which can be obtained in great quantities, was well studied by Miescher (1874). According to Posner (1888) the spermatic fluid contains also an albumose and *spermin* (to which is due the characteristic odour) which arise from the prostatic secretion.

The spermatozoa contained in a cubic centimetre of semen are very variable in number. According to the observations of Lode (1891) they diminish gradually until they disappear altogether in ejaculations which follow one another rapidly. It is found, however, that after an interval of two days the number of spermatozoa contained in the seminal fluid is greater than after a suspension of sexual intercourse for six days. According to Lode the average number is about 60,000 per cubic millimetre and the total number in a normal ejaculation would reach the average figure of 226 millions. The greatest number of spermatozoa contained in an ejaculation would be 551 millions—the least 0.

The complete absence of spermatozoa in the seminal fluid (*azoospermia*), in cases in which it does not depend on premature ejaculations rapidly succeeding one another, has been described as a pathological condition during which there may be seminal ejaculations more or less normal in manner and quantity, but without any fertilising power.

The spermatozoa contained in seminal tubes of the testicle and epididymis are immobile, while those in the semen move in a lively manner. Their mobility, therefore, is due to the secretions of the spermatic passages with which they are mingled during the act of ejaculation. The form of movement in the spermatozoa is similar to that which is observed in many flagellate protozoa.

It is a movement determined by the rapid bending and extension of the tail, whilst the head is inactive and is pushed forward (Hensen). Owing to the velocity of the movements an exact analysis of them is impossible in semen recently ejaculated. Nagel has observed in some spermatozoa a rotation along their longitudinal axis, so as to give a boring effect with the tapered extremity of the head, which some designate the *perforatorium*. The oscillatory as well as the rotary movements are considered by him as effects of the resistances opposed to progressive locomotion. According to Lott (1871) the velocity of movement of spermatozoa is 0.06 mm. per second, that is, 3.6 mm. per minute. This harmonises

well with an observation by Bischoff, who found spermatozoa in the ovary of a rabbit 9 or 10 hours after coitus. It is in virtue of their active locomotion that the spermatozoa are able to reach the ovum in order to fertilise it, ascending along the uterine tubes after overcoming the pressure exerted in the opposite direction by the ciliary movement of the tubal epithelium.

The spermatozoa exhibit a *positive chemotaxis* to the mucus of the cervix of the uterus, as one may indeed ascertain in microscopic preparations (Chrobak). They show, on the other hand, a *negative chemotaxis* in regard to the acid mucus of the vagina (Seligmann).

The most important researches on this question are those of O. Löws (1902), who has clearly demonstrated the chemotatic action of the uterine and tubal mucus, which is greater than that of a simple alkaline solution of equal concentration.

The vitality of the spermatozoa is very great. Under suitable conditions they can continue to live for several weeks even outside the male organ from which they arose. Ahlfeld has seen them alive and moving after having been kept in an incubator for eight days; Hausmann has found them alive in the female genitals a week after coitus, Dührssen after three weeks and a half.

By the addition of water to the semen the movements of the spermatozoa are arrested more or less rapidly according to the degree of dilution; but after being rendered immobile they can become active again on the addition of saline solutions which bring back the seminal fluid to the normal concentration. Even acid solutions do not inhibit the movements. On the other hand, weak alkaline solutions favour and increase their mobility and may even restore it after it has ceased. In the same way act solutions of sugar, urea, and some salts. Very strong alkaline solutions and also strong solutions of neutral substances (such as chloride of sodium, urea, sugar) inhibit the movements, and are harmless only in certain concentrations. Spermatozoa, as other cells of the body, are in a state of osmotic tension different from that of the protozoa which live freely in water.

Different temperatures also act on the vitality of spermatozoa. The *optimum* for their mobility is 35° (Engelmann). The upper limit is 43°-44° for human semen (Mantegazza). Cooling retards and suspends the movements, but they can be brought back to their former state even after the semen has been maintained at 0° for six days (Mantegazza). The revivifying of the spermatozoa is possible even after subjecting them to the intense cold of - 15°.

II. The sperm formed by the *convoluted seminiferous tubules* collects in the straight tubules which pass through the spongy spaces of the corpus Highmori, in the *rete testis*, the efferent tubes, the canals of the lobules of the epididymis, and the vas deferens (Fig. 22).

The epididymis, like the testicle, is divided into lobules called

coni vasculosi, 8-10 mm. in length, in which are compressed in a small space tortuous canals about 20 cm. long, and with ampullary dilatations along their course. The union of the canals of the *coni vasculosi* forms the single, tortuous, *collecting canal of the epididymis* which is continuous with the *vas deferens*. The wall of the *effluent ducts* and of the tubules of the *coni vasculosi* consists of a *membrana propria* lined by ciliated epithelium; the movement of the cilia is in the direction of the canal of the

epididymis, thus favouring the progression of the spermatozoa, which are still incapable of active movement. In the canal of the epididymis there is, in addition to the epithelium, a layer of *smooth muscle* and a *tunica adventitia*, which is continuous with the interstitial connective tissue. The epithelium becomes much longer and presents a border of hair-like processes (Fig. 23). At the base of the cylindrical cells is a layer of small spheroidal cells, destined to take the place of the cylindrical cells, which become detached through age, and possessing, it may be, a secretory function as is the case in the cylindrical cells. The elaborated secretion flows into the interior of the canal, dilutes the mass of the spermatozoa, serves them for nutrition, and maturation, and renders them



FIG. 22.—Testicle, epididymis and vas deferens injected. (Kölliker from Arnold.) *a*, body of testicle; *b*, lobules; *c*, straight tubules; *d*, rete testis; *e*, small effluent ducts; *f*, lobules of epididymis or *coni vasculosi*; *g*, epididymis; *h*, vas deferens; *i*, vas aberrans inferior; *m*, branches of the internal spermatic artery which go to the testicle and epididymis; *n*, union of it with a branch of the spermatic; *o*, artery of vas deferens; *p*, union of it with a branch of the spermatic.

capable of active movement. The epididymis is also invested with a *tunica albuginea*, similar to that of the testicle and containing smooth muscle fibres.

At the inferior pole of the testicle the *canal of the epididymis* assumes the name of *vas deferens*, which is about 45 cm. long. In it are to be distinguished the convoluted *testicular* portion, the *funicular* contained in the spermatic cord within the scrotum, the *inguinal* which passes through the inguinal canal, and, lastly, the *pelvic* or *descending* portion found in the pelvis, and opening

—united with the canal of the *vesiculæ seminales*—into the *ductus ejaculatorius* (Figs. 24, 25, and 26).

Its calibre increases along the testicular portion, then becomes

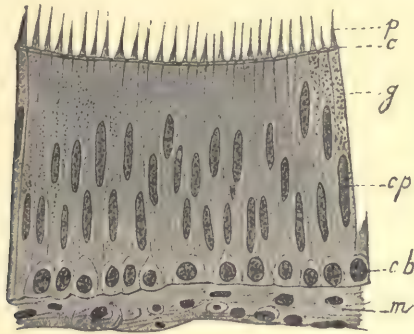


FIG. 23.—Section through the epithelium of the canal of the epididymis. Magnified 700 diameters. (Kölliker.) *m*, connective tissue and muscle fibres; *cb*, basal epithelial cells; *cp*, ciliated cells; *g*, granules of pigment; *c*, cuticular border; *p*, cilium.

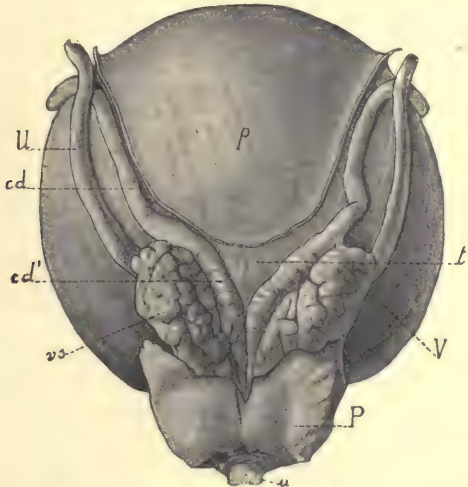


FIG. 24.—The base of the urinary bladder of man, and its relations to the prostate, the vesiculæ seminales, and the vasa deferentia. *V*, bladder; *U*, ureter; *P*, prostate; *u*, urethra; *vs*, vesicula seminalis; *cd*, vas deferens; *cd'*, ampulla of vas deferens; *t*, triangle included between the ampullae of the vasa deferentia and the line of reflection of the peritoneum from the bladder on to the rectum in the vesico-rectal cavity; *p*, peritoneum.

uniform (2-3 mm.), and so remains as far as the lowest part of the pelvic portion, when it becomes fusiform, flattened, and assumes the name of *ampulla*. Its surface becomes unequal and knobby, due to diverticula with blind ends arranged along the

axis of the principal canal (Fig. 26, *d*). The wall of the *vas deferens* is very strong, hard, and resistant to pressure; for this reason it is easily distinguished by digital examination from the other constituents of the *spermatic cord*. The wall is composed of a thick *mucous coat*, a still thicker *muscular coat*, and a thin *fibrous coat or tunica adventitia*.

In the vicinity of the *vas deferens* are found almost always longitudinal fasciculi of the internal cremaster muscle (Fig. 27, *f*).

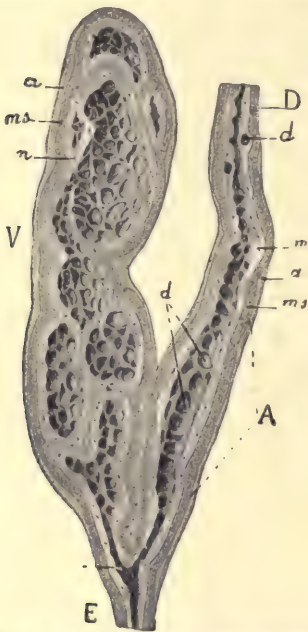


FIG. 25.—Vas deferens (left side) with ampulla and corresponding vesicula seminalis, in frontal section. (Disse.) *D*, vas deferens; *A*, ampulla; *V*, vesicula seminalis; *E*, ejaculatory duct; *d*, diverticula; *o*, opening of the vesicula seminalis into the ejaculatory duct; *m*, mucous coat; *ms*, muscular coat; *a*, tunica adventitia.

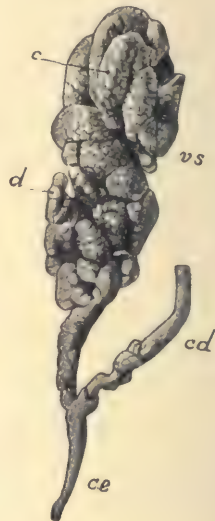


FIG. 26.—Model of the vesicula seminalis (right side) seen from the anterior face (from a preparation made by corrosion by Banchi). Natural size. *vs*, vesicula seminalis; *c*, its principal canal; *d*, a diverticulum; *cd*, vas deferens; *ce*, ductus ejaculatorius.

In the interior of the duct of virile subjects an abundant quantity of semen is found always.

The *ejaculatory ducts* are formed by the union of the narrow ends of the corresponding deferent ducts with the vesiculæ seminales at the base of the prostate. They traverse the prostate, and after a course of 15-16 mm., along which they become finer, they open by small elliptical orifices into the floor of the prostatic portion of the urethra, in the so-called *colliculus seminalis*. Their structure is similar to that of the vasa deferentia, but they have much thinner walls.

Their epithelial cells are secretory like those of the deferent duct. They serve as canals to convey into the urethra the spermatie secretion, as well as the secretion from the epididymis, the vas deferens, and the vesiculæ seminales.

Budge described peristaltic movements in the deferent duct of the rabbit and cat. These observations were confirmed by L. Fick, who saw, however, in the dog, instead of peristalsis, a diffuse contraction along the whole of the canal. In respect to the deferent duct of man, let us record an observation made conjointly by Kölliker and Virchow in 1852 on a man who had been executed. Electrical stimulation produced a strong contraction without peristalsis. But this does not exclude, according to Exner, the probability that in man also, under normal conditions the deferent duct and the ejaculatory duct empty themselves by peristalsis. He is certain that when one experiments with the isolated deferent duct the mere cooling of it occasions a very great contraction of the canal, which prevents observation of the peristaltic contractions.

With isolated vasa deferentia of the rabbit and cat in warm Ringer's solution, Nagel (1905) was able to observe accurately the response to electric and mechanical stimulation, and sudden warming and cooling. The result of all his observations is that the contraction of the entire canal, without any sign of progressive contractile waves, is the only effect to be seen on artificial stimulation.

The structure of the *ampulla* of the vas deferens is essentially similar to that of the vesicula seminalis, which is a lateral diverticulum in the form of a little sack placed immediately under the ampulla, before this is continued into the *ejaculatory duct*. The volume of the vesicula seminalis varies with age and with the degree of its fulness; its capacity is 1.5 to 2.5 c.c. The vesicula is in the form of a tube 10-12 cm. long, with a blind end, from

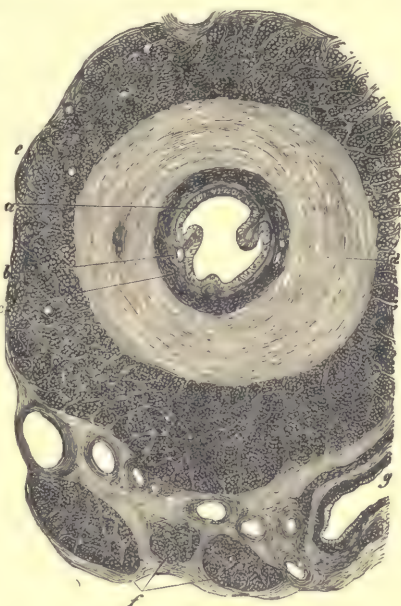


FIG. 27.—Section through the beginning of the vas deferens. (Klein.) *a*, epithelium; *b*, tunica propria and submucosa; *cde*, internal, middle, and external strata of the muscular coat; *f*, fasciculi of the internal cremaster muscle; *g*, section of blood-vessel.

the walls of which diverge many offshoots of various form and length. The walls of the vesicula consist of a *tunica mucosa*, a *tunica musculosa*, and a *tunica adventitia* (Fig. 25). The epithelial cells vary in form with age; in the newly born and the young child they are cylindrical, in the adult cubical and sometimes flattened. They are undoubtedly secretory. The secretion which is found in the cavity of the vesicula is a yellowish viscous substance, which, after death, or after ejaculation, takes a gelatinous form, or that of granules of sago, but later becomes fluid, and contains a globulin soluble in acetic acid. In animals a change of form has been observed in the secretory epithelium as the result of coitus, and the excitation of the secretory nerves (Stilling and Akutsu). During rest it is larger and richer in protoplasm than in the state of functional activity.

Besides the function of the glands in forming a special secretion, many physiologists have attributed to the vesiculæ seminales—as to the ampullae of the epididymis—also the office of reservoirs for the spermatic fluid produced by the testicles (*receptaculum seminis*). The question is not yet clearly settled, although in more recent times it is considered of greater importance than the secretory function. As to the physiological function of the secretion of the vesiculæ seminales it can only be affirmed that it is different in different animals. According to the observations of Leuckhart, in rodent animals, the secretion of the vesiculæ, mingling with the prostatic secretion during coitus, coagulates and forms a sort of plug which occludes the vaginal opening and prevents the escape of the semen, which otherwise might easily happen, owing to the excessive rapidity with which coitus is completed. In other animals, on account of the greater duration of the retention of the penis in the vagina, there is no need for the formation of a plug. In them the vesicular secretion serves to dilute the testicular and to facilitate its ejaculation. But that this dilution is necessary to render the sperm capable of fertilisation is neither proved nor probable, as Nagel justly notes.

Tarchanoff (1887), experimenting on frogs, concluded that the filling and the state of tension of the vesiculæ seminales determine the sexual need in the male, so that their removal or the evacuation of their contents is sufficient to make the embrace cease immediately; and, on the other hand, the simple injection of milk into the vesiculæ creates artificially the sexual need (*vide* Vol. IV. Chap. II. p. 82). Steinach, however (1894), was not able to confirm these results. He noted that the esculent frogs do not possess vesiculæ, and in the common grass frogs, on which Tarchanoff experimented, the embrace was observed several days before the vesiculæ were filled with secretion. He observed, moreover, that when the vesiculæ were extirpated before or during copulation, the embrace did not always cease, and that when the female was

detached from the male, he could copulate anew with her. In white rats, also, the sexual need is not abolished after extirpation of the vesiculae. After a time, however, such good results in breeding are not obtained as with the intact male. Similar results were obtained by Camus and Gley (1897). It does not appear to me, however, that these results are entirely opposed to the theory of Tarchanoff, even though they should oblige us to modify it. When the vesiculae are absent, as in the esculent frogs, or have been extirpated, as in the grass frogs, and in rats, the *ampullae of the deferent ducts*, which have the same structure as the vesiculae, may determine in a reflex way the sexual need. That, however, the vesicular secretion is not necessary for fecundation appears from the successful experiments on artificial fertilisation carried out on bitches by Ivanoff (1900) with sperm removed from the epididymis of the dog.

Lode (1895) is of opinion that the vesiculae cannot be considered as reservoirs of the sperm secreted by the testicles, because in that case unilateral castration ought to cause atrophy of the corresponding vesicula. Now that does not occur after extirpation of a testicle in the guinea pig. It is known, however, that bilateral castration in bulls and horses causes a diminution in size of the vesiculae, with atrophy of the glandular epithelium and hyperplasia of the connective tissue. Also, as regards man, the vesiculae of eunuchs are found to be atrophied and filled with mucous secretion.

Rehfishch (1896), after injections of the vas deferens with liquids of different kinds, saw the vesicula swell, before the liquid passed through the ejaculatory duct into the urinary passages. When in man pressure with the finger is applied through the rectum to the vesiculae to empty them of their contents, there is an escape of semen, which is mixed with the urine at the next micturition, or trickles directly through the urethra. On these grounds he considers that the vesiculae, besides being secreting organs, act also as reservoirs, in which is collected the sperm as it is formed in the testicles.

Fürbringer in sixty dead human bodies almost always found sperm in the contents of the vesiculae; Kayser confirmed this observation in seven men. But to the observations of Rehfishch, as well as to those of Fürbringer and Kayser, one may object with Nagel that the passage of the sperm into the vesiculae does not happen normally during life, but during the asphyxia of death, in consequence of the contraction of the vas deferens which forces the contained seminal fluid in the direction of the vesiculae. Exner put forward the hypothesis that in the vesiculae accumulates the sperm, which is formed and not emitted, during long sexual abstinence. The researches of Lode, however, are not favourable to this hypothesis. He observed that after long abstinence the first ejaculation contains a relatively small number

of spermatozoa compared with that which is observed in the ejaculations which occur with moderate frequency.

From the whole of the phenomena which we have reviewed it may be concluded that probably the vesiculæ seminales have no great importance as regards the *potentia coeundi* and the *potentia generandi*, although it cannot be denied that their secretion facilitates these two functions, either by diluting the testicular secretion or forming with it and with the prostatic secretion in the rodents a firm coagulum which occludes the vagina and prevents the escape of the semen, and in the other mammals and in man, a glutinous coagulum which is probably not without importance in facilitating the fertilisation of the ovum, by preventing the loss of the semen through the vulva.

III. The *prostate* is a solid glandular and muscular organ similar in form and dimensions to a chestnut; it is situated in the pelvis and through it pass the first portion (prostatic) of the *urethra*, and the two *ejaculatory ducts* (Fig. 28).

Its physiological activity is intimately connected with the sexual function; for it atrophies in the adult after castration, and if this operation be performed in infancy, the prostate does not develop. In animals it increases in size, as well as the testicles, at the time of rutting; in man it grows rapidly at the beginning of puberty, reaches its complete development at 25 years, and preserves its dimensions unaltered up to 40-45 years; it increases more or less in size in advanced age, until it creates a somewhat considerable obstacle to the regular and complete emptying of the bladder (*prostatism*). Smooth muscular tissue prevails in the structure of the prostate; the glandular part forms scarcely more than a third, or less than half of the total mass of the organ. It belongs to the type intermediate between tubular and alveolar glands. It is divided into a certain number (16-32) of glandular units of conical form, disposed radially around the urethra, into which opens their excretory duct. Each glandular unit is wrapped round by a stroma, formed of smooth muscle fibres with a few connective tissue fibres, elastic fibres, and vessels, and condensed at the periphery of the organ into a thick investing membrane.

The little excretory canals, fine near the outlet, increase soon in diameter and present numerous tubular and alveolar diverticula, which, still deeper, increase in number and size.

The tubules and glandular vesicles are lined by a cylindrical epithelium of varying height, containing granules of yellowish-brown pigment (Fig. 29). Almost constantly in the adult, and still more in the aged, are found in the larger vesicles of the prostate gland peculiar corpuscles, spherical or elliptical, colourless or brown, of a diameter of 0.3-0.5 mm., which present the reactions of *amyloid* corpuscles; these readily calcify, acquiring

the diameter of 1 mm., and may be expelled with the secretion. The glandular tissue increases in quantity up to mature age; later it diminishes, whilst the connective tissue augments and the organ assumes a greater consistency and hardness. Between senile impotence and senile hypertrophy of the prostate there is

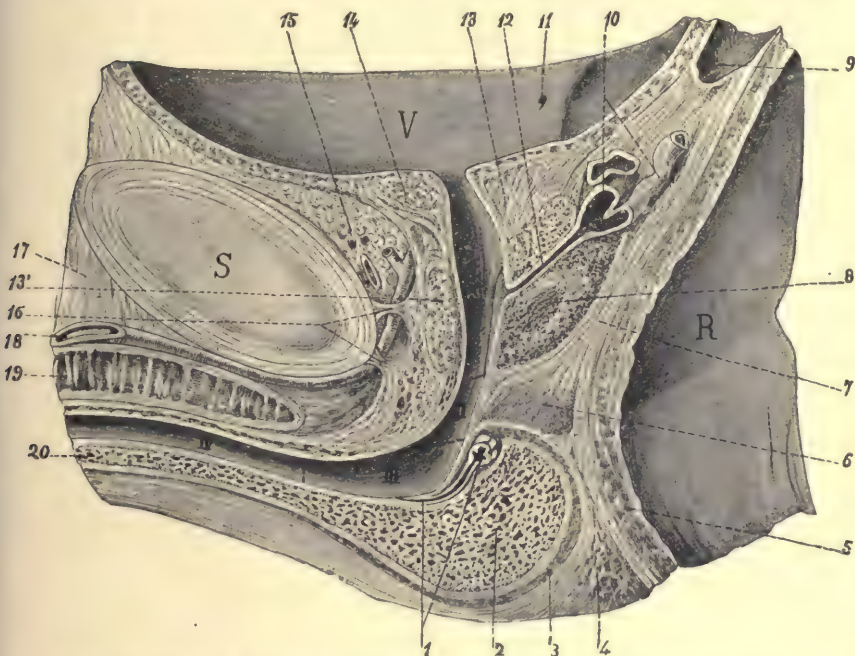


FIG. 28.—Median section through the fixed portion of the male urethra of an adult in a state of physiological dilatation, in its natural relations. (Waldeyer.) S, symphysis pubis; V, urinary bladder; R, rectum; I, prostatic urethra; II, membranous or trigonal urethra; III, pretrigonal urethra; IV, urethra cavernosa; 1, bulbo-urethral gland (Cowper's) and its excretory duct; 2, bulb of the urethra; 3, bulbo-cavernous muscle; 4, external sphincter muscle of anus; 5, internal sphincter muscle of anus; 6, muscle of urogenital trigone (the line points to part behind urethra); 7, rectovesical fascia; 8, prostate; 9, rectovesical hollow; 10, vesicula seminalis and deferent duct; 11, opening of ureter in ureteric fold; 12, ejaculatory duct; 13, internal sphincter of bladder; 13', surface which includes anterior part of internal sphincter of bladder, anterior part of prostate, and prostatic part of striated sphincter of urethra (the boundaries between these various organs are not distinct in the figure); 14, thickening of median layer of the circular fibres of the vesical muscles at the anterior circumference of the internal orifice of the urethra; 15, adipose tissue in the prevesical space; 16, medial puboprostatic ligaments; 17, suspensory ligament of penis; 18, deep dorsal vein of penis; 19, corpus cavernosum; 20, corpus spongiosum.

no causal relation such as exists between senile atrophy of the testicles and atrophy of the glandular portion of the prostate (Griffiths).

The secretion of the prostate is fluid, milky, slightly alkaline (according to Poehl slightly acid in the dead body, and according to Fürbringer also in the living), containing protein, but free from mucin. In the dead body it contains a great number of crystals

of *spermine* (which are absent in the living), to which, as we have remarked, the semen owes its characteristic odour.

Fürbringer has succeeded in obtaining the prostatic secretion of man during life. By pressure on the prostate, the glandular contents are expelled and collect in the urethra, from which they can be removed. The secretion has the capacity of effecting movement in the spermatozoa by some special action, and not only by acting as an indifferent liquid which dilutes the semen. In excessive quantity it proves harmful to their vitality, probably owing to the development of an acid. This property of activating the spermatozoa does not belong inclusively to the prostatic secretion,

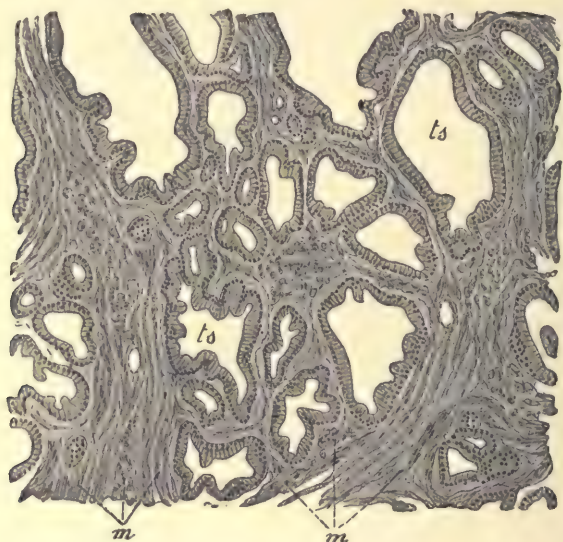


FIG. 29.—Section of prostate of adult man. Magnified 45 diameters. (Sobotta.) *ts*, tubules and glandular vesicles; *m*, bundles of smooth muscular fibres of the stroma.

but also, as we have noted, to the secretion of the epididymis (specially of the ampulla). In fact, spermatozoa collected directly from the epididymis of the guinea-pig move in as lively a manner as those which have been subjected to the influence of the prostatic secretion (Exner and Nagel). Fürbringer, however, maintains that the prostatic secretion renders these movements more active. Steinach observed that the spermatozoa of rats continue to move for a longer time when a little sodium chloride solution is added to the prostatic liquid.

Walker (1899) carried out a systematic series of researches on the sperm of the dog, and arrived at the following conclusions:

(a) The sperm drawn from the testicles shows no active movements.

(b) The sperm drawn from the head of the epididymis likewise.

(c) Sperm drawn from the tail of the epididymis presented slight active movements in those parts of the preparation in which it was diluted.

(d) The sperm of the deferent ducts also presents movements in the diluted parts of the preparation, but no movement where the liquid is more dense.

(e) The testicular sperm mixed with prostatic secretion shows undoubted movements, but only slightly active.

(f) The sperm of the epididymis mixed with prostatic secretion shows lively movements.

(g) Finally, the sperm of the epididymis diluted with solution of chloride of sodium shows also lively movements at the points where the liquid has been well mixed.

From his observations Walker draws the conclusion that the prostatic secretion stimulates the spermatozoa to movement by diluting the liquid; but it contains also nutrient substances for the spermatozoa, and this explains the fact observed by Steinach, the greater duration of the movements of the spermatozoa when they are immersed in the prostatic secretion.

Fürbringer observes that in spermatic emission without coitus (spermatorrhoea) the spermatozoa move very weakly, whilst in the semen emitted during coitus they move quickly. This he explains by the theory that the stimulating action of the prostatic secretion is wanting in the first, but is present in the second case.

The prostate has a double innervation: it receives purely motor fibres from the *nervus erigens* and motor and secretory fibres from the hypogastric nerve. On stimulation of the first in dogs, Eckhard (1863) saw the prostatic contents voided through the urethra, but the flow ceased if the stimulation was continued after the expulsion. The *nervus erigens*, therefore, limits its action to the muscular fibres of the gland, expressing the secretion which has accumulated there. The same fact was confirmed by Mislowsky and Bormann (1898), but they found besides that the excitation of the *hypogastric nerve*, which emerges from the *inferior mesenteric ganglion*, produces a continuous secretion, acting not only on the muscular fibres, but also on the secretory epithelium of the gland. Atropine checks the secretory action, while pilocarpine causes a continuous secretion. Excitation of the central branch of the hypogastric causes secretion by the gland in a reflex way through the nerve of the opposite side. The *inferior mesenteric ganglion* acts as centre of the reflex, because the secretory effect persists even after this ganglion is separated from the rest of the sympathetic and spinal system. We shall view in due time the participation of the prostate in the function of spermatic ejaculation.

Worthy of consideration also are the *bulbo-urethral* or *Cowper's glands*, which have a tubulo-alveolar structure similar to that of the prostate. They are two small glands of the size of a pea, but they can be much larger. They are placed at the side of the median line between the posterior part of the urethral bulb, and the membranous urethra (Fig. 28, 1). Their excretory ducts are 3-4 cm. long and open on the inferior border of the bulbar fossa of the urethra with little cleft-like orifices. *Cowper's glands* are surrounded by smooth muscular fibres, on which are also superimposed strands of the *bulbo-cavernosus muscle*, which, contracting, can compress the gland and squeeze out the contents. The secretory cells are supplied by the *nervus pudendus*. The secretion of Cowper's glands is a viscous alkaline liquid of the importance of which little is known. Probably their function is similar to that of the little alveolar glands which are scattered throughout the whole course of the urethral mucous membrane. Stilling is of opinion that this secretion serves to secure an alkaline reaction to the urethral mucus, which, after micturition, may be acid, and harmful to the vitality of the spermatozoa. It has been observed that in eunuchs the glands of Cowper do not atrophy; this would exclude the view that their activity is confined to the sexual function. Hugier, however, observed that they increase in size at the time of puberty; Schmidemühl found that they diminish in castrated animals, and Stilling described the changes which they undergo after long abstentions, or repeated coitus. It is then clearly demonstrated that they participate in the sexual functions, and empty their contents during copulation.

IV. The copulatory organ is represented by the *virile member* (*penis*), in which are distinguished a *root* (or fixed perineal portion), and a *body*, and *glans*, which constitute the free, pendulous, copulatory portion.

It varies much in volume and dimensions according to the state of flaccidity or erection. In the adult the free part of the flaccid penis has an average length of 10 cm. and a circumference of 9 cm.; in complete erection it reaches an average length of 15 cm. and a circumference of 12 cm. Independently of the state of erection, the dimensions of the penis vary much, from extreme cases of excessive smallness, dependent on arrest of development, to cases of development so great that coitus is difficult or impossible.

The penis is constituted in great part of erectile tissue disposed in three long masses, almost cylindrical, enclosed in fibrous sheaths and united in such a way as to form a three-faced prism with rounded edges, and covered by a common integument.

These three masses are the two *corpora cavernosa* of the *penis*, and the *corpus spongiosum* or *corpus cavernosum* of the *urethra*,

surmounted at the extremity by the *corpus spongiosum* of the *glans* (Figs. 30 and 31).

The *corpora cavernosa* of the *penis* correspond to the dorsum and sides of the penis itself. The *erectile tissue* is covered by a dense fibrous membrane, extensile and elastic, and called the *tunica albuginea*, which sends into the interior radiated prolongations. It is a spongy vascular tissue, in which the inter-communicating lacunae consist of enormously dilated venous spaces, intercalated between the extremities of the arteries and the capillaries, and the beginning of the veins (Fig. 32). They are formed by innumerable lamelliform

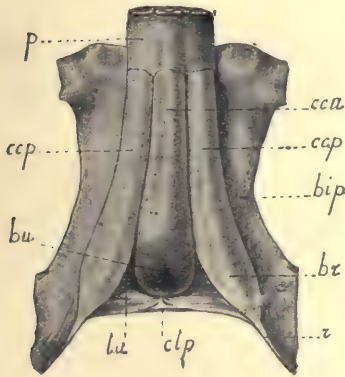


FIG. 30.—Root and posterior part (pars perinealis) of the body of penis seen from below, after removal of the integument and muscles. *ccp*, *ccp*, corpora cavernosa of penis; *br*, bulb of root of corpus cavernosum; *r*, extremity of root of corpus cavernosum; *cca*, corpus spongiosum; *bu*, bulb of urethra; *p*, skin of penis; *bip*, ischiopubic arch; *tu*, urogenital trigone; *clp*, tendinous centre of perineum.

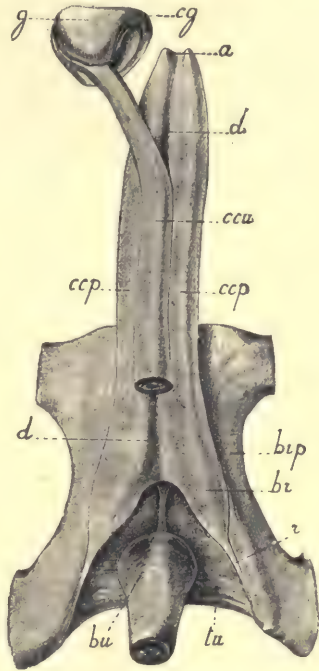


FIG. 31.—The penis from below, after the corpora cavernosa have been laid bare. The corpus spongiosum has been cut in front of the bulb, and this is turned aside. In front the corpus spongiosum and the glans are isolated and detached from the corpora cavernosa of the penis. *d*, *d*, ventral depression or conduit between the two corpora cavernosa, which receives the corpus spongiosum; *a*, anterior extremity of the corpora cavernosa; *g*, glans; *cg*, corona of glans. The other indications as in preceding figure.

or filamentous *trabeculae*, which circumscribe spaces of varied form and size. The trabeculae consist for the most part of smooth muscular fibres interwoven in a diversified way, mixed with a network of connective tissue and elastic fibres. Their surface is covered by an endothelial layer which lines the small spaces.

The *corpus spongiosum* or *corpus cavernosum* of the *urethra* is a median organ situated ventrally in respect to the corpora

cavernosa of the penis, and forms a sheath to the urethral canal. It commences as the *bulb of the urethra* which increases in volume at puberty, reaches in the adult the size of a filbert, and hypertrophies in old age. It continues along the free part of the penis, in cylindrical form, and terminates in the *corpus*

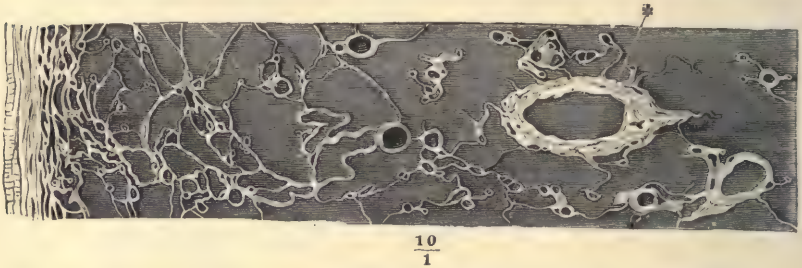


FIG. 32.—Portion of a section of a corpus cavernosum of the penis injected from the deep artery of the penis. (Henle.) Magnified 10 diameters. To left tunica albuginea; * section of deep artery of penis.

spongiosum of the glans. Its structure differs in some particulars from the corpora cavernosa of the penis (Fig. 33). The *cavernous spaces* are very small; the *trabeculae* which form them are thicker, richer in connective tissue, and relatively poorer in muscular

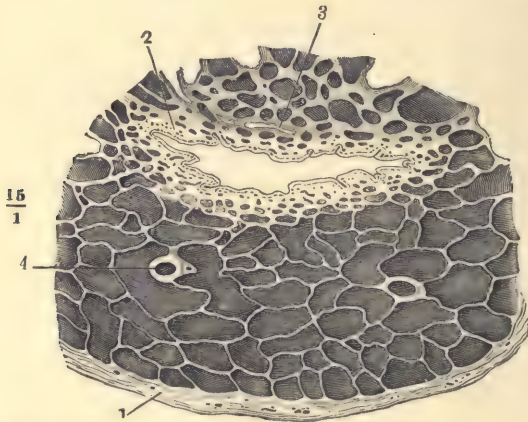


FIG. 33.—Part of section of corpus spongiosum or corpus cavernosum of urethra injected from its artery. (Henle.) Magnified 15 diameters. 1, tunica albuginea; 2, urethral mucous membrane; 3, section of a blood space in the mucosa; 4, section of an artery.

fibres. The blood spaces of the corpus spongiosum do not communicate with those of the corpus cavernosum of the penis; the communications, however, between the corpus spongiosum and that of the glans are numerous. The *corpus spongiosum of the glans* forms a sort of mushroom head which receives in its

concavity the pointed extremities of the corpora cavernosa of the penis and the corpus spongiosum of the urethra. From the fibro-elastic sheath of the urethra emanate and radiate in every direction delicate laminae of connective tissue; these pass through the corpus spongiosum of the glans, which has the character of a venous maze, rete mirabile, rather than of true cavernous tissue. The veins which form it are wide, repeatedly anastomose, and are provided with a thick tunic of muscular fibres disposed circularly and in part longitudinally (Fig. 34).

The passage of the blood from the arteries into the system of cavernous spaces of the erectile tissue of the penis takes place in part through the capillary network, in part directly, as by the

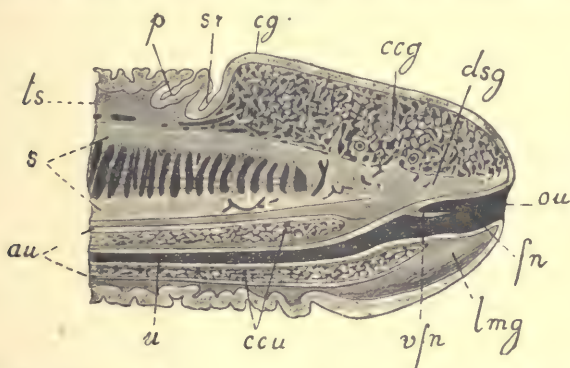


FIG. 34.—Sagittal section through the glans, and the anterior part of the body of the penis. (Eberth.) *s*, septum of penis (septum pectiniforme); *u*, canal of urethra; *fn*, fossa navicularis; *vfn*, valve of the navicular fossa; *ou*, external orifice of urethra; *ccu*, corpus spongiosum of urethra; *au*, tunica albuginea of *ccu*; *p*, prepuce retracted behind the glans; *ts*, tela subcutanea; *sr*, retroglandular furrow; *cg*, corona of glans; *ccg*, corpus spongiosum of glans; *dsg*, fibrous prolongation of extremity of corpus cavernosum of penis (dorsal part of septum of glans); *lmg*, medium ligament of glans (ventral part of septum of glans), in connection with frenum of prepuce.

arteriae helicinae. These have a spiral course which facilitates their lengthening during erection. They have well-developed circular muscles, and often possess longitudinal muscular fibres also.

From the physiological point of view it is noteworthy that in many small arteries of the penis, especially in the *helicine arteries*, the intima appears to be folded; this renders it capable of great dilatation during erection, and limits the area during flaccidity (Ercolani, 1869). But still more interesting is the fact observed by Ebner (1900) that these arteries present here and there a peculiar thickening of the intima, in the form of a little cushion projecting into the interior of the vessel; it is traversed by elastic fibres continued from the membrana elastica interna, and by longitudinal muscular fibres (Fig. 35). These little cushions have apparently the function of a valvular apparatus, which occludes,

more or less completely, the interior of the vessel, and limits the afflux of blood to the corpora cavernosa whenever the strong muscular coat assumes the tonus which exists when the penis is flaccid. The muscular fibres also of the trabeculae of the cavernous tissue which bounds the spaces must contribute to restrict the capacity of these, during the state of tonicity which exists during the flaccid state of the penis. When, therefore, all the muscular elements, whether of arteries or of trabeculae, contract actively, as happens for instance during a cold bath, there is observed a diminution in the size of the penis to about one-sixth or one-fifth its volume in its general state of flaccidity; this fact demonstrates that in these circumstances the penis empties itself almost completely of the blood contained in the vessels or in the cavernous

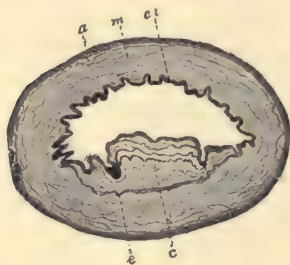


FIG. 85.—Transverse section of an artery of the bulb of urethra of man; the elastic fibres and membranes were coloured in the preparation. (Eberth.) Magnified 182 diameters. *a*, tunica adventitia; *m*, tunica muscularis; *ei*, internal elastic membrane; *c*, little valvular cushions of the intima, projecting into cavity and traversed by elastic lamellae; *e*, elastic lamella at periphery of cushion.

spaces. When, however, sexual excitement begins, all the muscular fibres with which the penis is provided expand actively, the helicine arteries lengthen and become distended, the little valvular cushions with which they are provided are drawn back eccentrically, the cavernous spaces dilate, and the blood impelled by the rhythmic action of the heart can penetrate freely from the arteries into the corpora cavernosa under strong pressure, and bring about that great increase in the volume and rigidity of the penis which is observed during erection.

Numerous experiments were carried out to illustrate the changes which the circulation of the blood in the penis undergoes during erection. This important phenomenon which renders sexual intercourse possible needs a short historical account. Regner de Graaf was the first in 1668 to produce erection of the penis in the dead body by injection of the vessels; he saw that it increased by four or five times its volume, became hard, and curved on the dorsal surface, erecting itself and adapting itself to the curve of the vagina into which it must be introduced during coitus. The *increase in size and rigidity* of the penis depends essentially, therefore, on the forcible filling and tension of all its blood-vessels and cavernous spaces, and its *erection* does not depend on the contraction of any muscle, but is a passive mechanical effect, due to the fact that the dorsal fascia of the penis is more tense, being shorter, than the ventral, on account of which the penis must necessarily be curved dorsally and erected when it increases in size and length.

To account for the mechanism of erection, the Ancients imagined that a mechanical obstacle to the circulation of the blood in the organ arose during the venereal orgasm, producing a stasis of blood in the lacunae of the corpus cavernosum, and they believed that they found this obstacle in the compression of the *vena pudenda interna* against the symphysis of the pubes. Cuvier and Adelon, finding this cause insufficient, surmised that there was a spasm of the veins emerging from the penis, and thus less blood would leave the organ than entered it. But it was soon seen that the simple idea of blood stasis had not any value. Burdach observed that the arteries of the penis in erection pulsate with greater force, and that erection was never obtained by complete ligature of the veins of the penis. Erroneous, therefore, is also the theory of Krause and Kobelt, who attributed the blood stasis and consequent erection to the spastic contraction of the ischio- and bulbo-cavernosus muscles. Valentin was of opinion that the contraction of the muscular fibres of the trabeculae pulled apart the walls of the lacunar system of the corpora cavernosa, and thus enabled the cavernous spaces to receive a greater quantity of blood. But Rouget in 1858 successfully combated this doctrine; he pointed out that the corpora cavernosa as fibrous tubes, whose interior is crossed by muscular divisions stretched from one wall to the other, could only be diminished in capacity by the contraction of the muscles. In proof of this he adduced the effects of electrical stimulation and cold, which produce a diminution in volume of the organ, accompanied by a kind of rigidity different from that which occurs in erection.

Kölliker (1852) came to the conclusion that in erection there is no contraction, but transitory paralysis of the muscular fibres of the trabeculae of the corpora cavernosa. Milne Edwards (1868) combined Kölliker's view with that of Kobelt on the contraction of the ischio- and bulbo-cavernosus muscles. But M. Schiff (1868) disproved this opinion by a simple experiment. If all the nerves of the penis are cut, the organ becomes engorged with blood owing to neuro-paralytic hyperaemia, but becomes softer than in its normal state.

The theory of erection first received a true experimental basis with the discovery of the *nervi erigentes*, made by Eckhard in 1863. These nerves arise from the sacral plexus, and in the dog come from the second, rarely from the third, pair of sacral roots; along the course of the nerves are intercalated some little ganglia. Eckhard found that electrical stimulation of these nerves produced a turgid condition of the penis, which begins at the bulb of the corpus spongiosum of the urethra, advances, and then spreads over the corpora cavernosa of the penis. If one of the corpora cavernosa be cut transversely, the blood escapes slowly from it in drops, presenting the dark colour of venous blood; a few seconds after

excitation of the nerve, the blood flows from it abundantly with the bright colour of arterial blood. If before the stimulation of the nerve the *vena pudenda communis* is cut, little blood flows from it; during stimulation of the nerve the outflow of blood becomes about eight times greater. If the *vena dorsalis* is cut, the escape of blood becomes fifteen times greater during excitation than it was during rest. All these facts demonstrate that the *nervi erigentes* are vaso-dilator.

Lovén (1866) confirmed these results of Eckhard. In addition, he observed that from the small arteries of the penis the blood spurts out with force during excitation of the *nervi erigentes*, and found in these vessels a notable augmentation of arterial pressure, which even reached six-tenths of that of the carotid. Nikolsky (1879), by introducing a cannula into the dorsal vein of the penis, produced a new confirmation of Eckhard's results, and considered the *nervus erigens* as an inhibitory nerve analogous to the cardiac vagus.

More extensive systematic researches on the increase of pressure in the arteries and veins of the penis during erection were carried out by François-Franck (1895), who applied to these inquiries the graphic method already attempted with sparse results by v. Anrep and Cybulsky (1884) and by Piotrowski (1887). François-Franck experimented on dogs, introducing into the dorsal artery and vein of the penis in the peripheral direction two cannulae to register manometrically the pressure in them. At the same time he was able to register the changes in the volume of the glans by inserting between it and the prepuce a large glass tube, fixing it there with a ligature, and connecting the narrow end to a Marey recording tambour.

The result obtained is represented clearly in Fig. 36. In A one sees that stimulation of the *nervus erigens* produces after a latency of $2\frac{1}{4}$ seconds an increase of size in the glans, which reaches its maximum 3 to 4 seconds after the stimulation has ceased, and then subsides.

In B is observed the inverse phenomenon, that is the diminution in volume of the glans following stimulation of the *nervus pudendus*. In Fig. 37, besides swelling of the glans owing to excitation of the *nervus erigens*, there are observed the contemporary increase of pressure in the vein, and the relative diminution of pressure in the artery. This last phenomenon is easily explained when one remembers that the cannula is in the peripheral end of the artery and is partially emptied during erection, owing to the active dilatation of the lacunar system of the corpus cavernosum, with which it directly communicates.

During complete erection, owing to the turgidity and lengthening of the penis, its cutaneous integument is passively distended, and the prepuce, through the swelling of the glans, slips behind

the corona. As the complete unsheathing of the glans is hindered when the frenulum preputii (the objective sign of *male virginity*) is intact, it is torn during the first sexual connection, with some

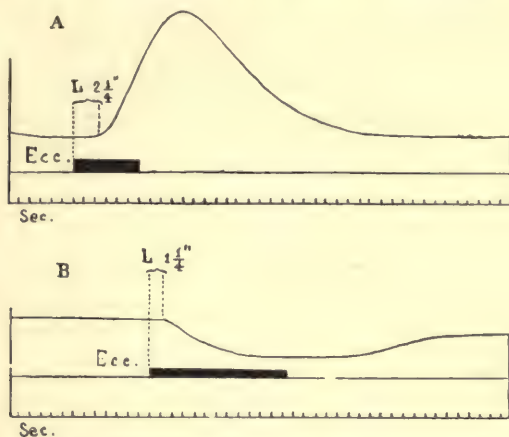


FIG. 36.—A, swelling of the glans of a dog as the result of stimulation of the *nervus erigens*; B, diminution of same following electrical stimulation of the *nervus pudendus*. (François-Franck.)

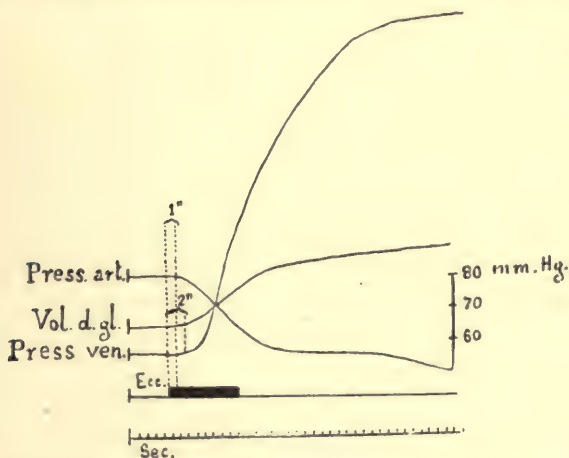


FIG. 37.—Simultaneous records of swelling of the glans of dog (as the result of electrical stimulation of the *nervus erigens*) and of the blood pressures in the dorsal artery and vein of the penis. (François-Franck.)

effusion of blood which corresponds to what is called *defloration* in the female sex.

V. *The erection of the penis* is the preparatory act for the *ejaculation of the semen*, which is a mixture of the secretions of the testes, the vesiculæ seminales, the prostate, and Cowper's glands. Ejaculation occurs when the erotic orgasm has reached its

greatest degree of intensity, even independently of coitus, that is from strong reflex excitement caused by contact and friction of the sensitive mucous covering of the glans with that of the vagina. It is probable, but not demonstrable, that during the venereal excitement which promotes erection of the penis there should be an increase in the metabolic activity of all the secretory organs which compose the male genital apparatus, which, augmenting the filling and tension of the whole system of canals, increases in a reflex way the nervous excitement, and promotes the erotic orgasm which immediately precedes the spermatic ejaculation. But this is essentially the mechanical effect of a series of movements caused by muscular activity.

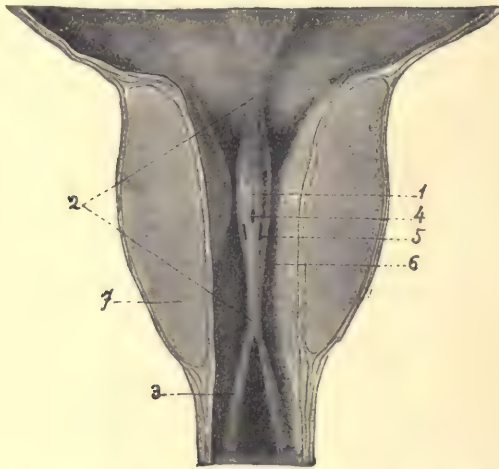


FIG. 38.—Prostatic urethra and membranous urethra, opened by a median incision in the anterior wall. (Chiarugi.) 1, *colliculus seminalis*; 2, urethral crest; 3, frenum of urethral crest; 4, orifice of prostatic utricle; 5, orifice of an ejaculatory duct; 6, orifices of prostatic glands; 7, surface of section of the prostate.

The contraction of the muscular fibres which are found in the septa of the testicles, and specially the peristaltic contractions of the walls of the vas deferens, and the simultaneous contractions of the muscular fibres of the ampulla of the epididymis, and of the vesiculæ seminales, produce a propulsion of all the secretions accumulated in these organs, impelling them—along the ejaculatory ducts—into the *prostatic urethra*, where the ejaculated fluid mixes with the prostatic secretion which has been at the same time expelled (into the urethra) by the contraction of the muscular elements of the prostate. In fact, the numerous punctiform orifices of the prostate gland open in close proximity to those of the ejaculatory ducts, below the *colliculus seminalis* and at the sides of the urethral crest (Fig. 38).

For the propulsion of the seminal fluid along the urethra to the meatus, from which it spirts out in successive jets, rapidly following one another with irregular rhythm, there enter into play other expulsive forces, developed by the smooth and striated muscles with which the prostatic and membranous parts of the urethra are provided. The *smooth muscle* is disposed in two strata—an *internal longitudinal*, which may be considered as the continuation of the muscular tunic of the bladder, and the muscular portion of the corpus spongiosum of the urethra, and an *external circular layer* which anatomists call the *internal sphincter of the bladder*. The *striated muscle* is in fibres disposed circularly, and constitutes the *sphincter* of the *prostatic and membranous parts of the urethra* of Henle, forms the essential part of the muscle of the urogenital trigone, is prolonged distally towards the beginning of the corpora cavernosa of the penis, and continues straight on with the deep part of the bulbo-cavernosus muscle (Figs. 39 and 27).

The smooth muscle of the urethra, the contraction of which is involuntary in type, causes the closure of the internal opening of the urethral canal, which renders difficult the emptying of the bladder in semi-erection of the penis, and prevents it altogether when erection is complete. During the reflex ejaculatory act it contributes to the expulsion of the semen along the urethra, and prevents it ascending in a retrograde direction towards the neck of the bladder. Walker (1899) is of opinion that the contraction of the internal longitudinal portion of this muscle produces a dilatation and shortening of the membranous urethra, and thus facilitates by aspiration the escape of the spermatie and prostatic secretions; whilst the contraction of the external circular portion, which follows at intervals, prevents the reflux of the seminal fluid into the bladder and impels it towards the external meatus of the urethra. If it could be shown that the two parts of the muscle

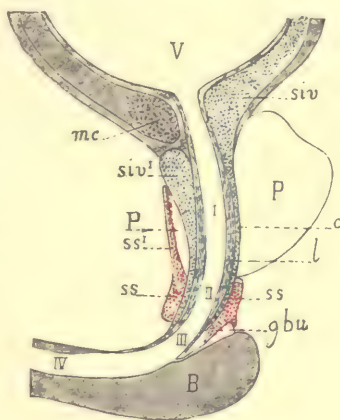


FIG. 39. — Diagram showing in sagittal section the muscular apparatus of the urethra. The smooth muscles are indicated in blue and the striated in red. (Chiarugi.) V, bladder; P, P, prostate; B, bulb of urethra; I, prostatic urethra; II, trigonal membranous urethra; III, pre-trigonal urethra; IV, urethra cavernosa; mc, thickening of median stratum of muscles of bladder, corresponding to anterior outline of internal orifice of urethra; siv, posterior segment of the internal sphincter of the bladder in continuation of the musculature of the trigonum vesicale; siv', anterior segment of internal sphincter muscle of bladder; c, external circular stratum of smooth muscle of urethra; l, internal longitudinal stratum of same; ss, ss, trigonal and bulbo-urethral part of striated sphincter of urethra; ss', prostatic portion of same.

were dominated by two distinct nervous impulses which alternate and follow one another rhythmically, this ingenious theory would find an experimental basis.

In any case one must reject the old opinion first expressed by E. H. Weber in 1836, which ascribed to the *colliculus seminalis* (called also the *caput gallinaginis* and *veru montanum*) the office of closing the urethral canal and making micturition difficult or impossible during erection.

The colliculus has not the structure of an erectile organ, and for this reason is incapable of occluding the urethra; on the other

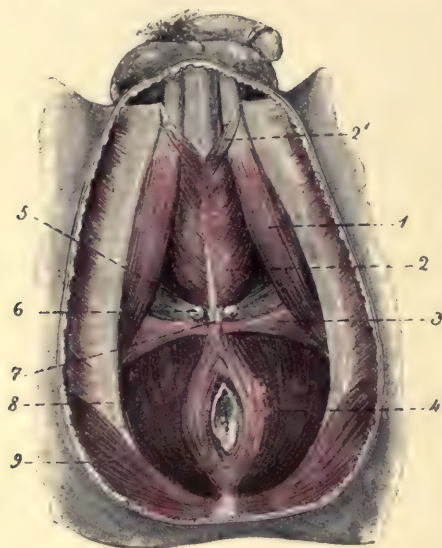


FIG. 40.—Superficial muscles of the perineum in the male. (Chiarugi.) 1, ischio-cavernosus muscle; 2, bulbo-cavernosus muscle; 2', constrictor radialis penis of the bulbus cavernosus which forms the loop of Houston; 3, transverse superficial muscle of perineum; 4, external sphincter of anus; 5, urogenital trigone, inferior surface; 6, bulbo-urethral gland; 7, tendinous centre of perineum; 8, levator ani; 9, gluteus maximus.

hand, if the colliculus through the effect of muscular contractions could obstruct the urethral canal, at the same time would be occluded the orifices which admit into it the secretions of the testicle and prostate; and thus—as Walker justly notes—their ejaculation externally would be prevented.

The expulsive action of the smooth muscle of the urethra is helped greatly by the reflex or voluntary contraction of the *external striated sphincter* of Henle, the bulbo-cavernosus muscle which embraces the bulbar portion of the corpus spongiosum, and the ischio-cavernosus muscle which surrounds the roots of the corpora cavernosa of the penis (Fig. 40). The contraction of these muscles is repeated in a more or less distinctly

rhythmical manner until all the semen is ejaculated from the meatus externus of the urethra. On this rhythm in the contraction of the muscles of expulsion depends the emission of the seminal fluid in jets.

VI. In treating of the sexual instinct (*vide* Vol. IV. Chap. II. 5, pp. 78-91) we described the phenomenon of puberty, and indicated the central and peripheral conditions of the several senses which determine sexual excitement, and finally the active intervention of almost the whole nervous system, both central and peripheral, of animal life, directed to promote the physiological processes which secure the fundamental phenomenon of fertilisation of the ovum and the consequent reproduction of the species. Here it only remains to complete the treatment of the subject, to consider especially the nervous pathways and centres on which the reflexes, erection of the penis, and ejaculation of the seminal fluid depend.

The different central and peripheral stimuli evoke spermatic ejaculation, the more easily and tumultuously the greater the abundance of the accumulated secretions and the tension which they produce in the seminal passages and the corresponding glands. According to the observations of Lode, accumulation of the secretions does not go on continually during abstinence, but is suspended after some days. During prolonged abstinence the secretions are probably reabsorbed only to a small extent by the lymphatic ducts, because *spontaneous pollutions* occur normally during sleep, accompanied almost always by erotic dreams so vivid as to leave remembrance and sometimes to cause awakening. After puberty, and generally during early manhood, these pollutions occur somewhat regularly every two or three weeks in individuals who are chaste and abstinent. With the first pollution of spontaneous origin or provoked by masturbation puberty is initiated in the male, as with the first menstruation in the female; it occurs usually about a year later in the former than in the latter, and in our climate at the age of about fourteen to fifteen years. The normal generative capacity ceases in woman at the so-called climacteric age, whilst in man it is prolonged usually to a very advanced age, and does not cease entirely until extreme old age.

The reflex centres for erection and ejaculation are, according to the great majority of physiologists, situated in the lower segments of the lumbar spinal cord. From the experiments of Goltz on dogs (1874) it is evident that after transverse section of the spinal cord between the last dorsal and first lumbar vertebra, and the disappearance of the depressing effects of the operation, it is possible by friction of the penis, or suitable mechanical stimulation of the skin of the perineal region, to provoke not only the phenomenon of erection, but also that of spermatic ejaculation. When the bladder of the dog is full, it is sufficient sometimes to

raise the trunk of the animal into a vertical position to see the penis become erect and, after more or less prolonged mechanical excitation, to witness emission of the seminal fluid. The same fact had already been observed by Brachet many years before (in 1839). More recently L. R. Müller (1902) has observed that the reflexes of erection and ejaculation are preserved even after extirpation of all the lumbar and the upper portion of the sacral region of the spinal cord. It is only necessary that the conus and epiconus medullaris should remain intact. On the other hand, it is noted by pathologists that in man incapacity of erection is connected with diseases of the terminal segments of the spinal cord (Clemens and others).

But although from these experiments and clinical observations it follows that the integrity of the lower sacral segments is necessary for erection and ejaculation, it is not demonstrated in an adequate manner that the nerve-cells contained in these parts represent the *central organ* for those functions. The possibility is not excluded that only the most important nerves of the reflex come from the terminal portion of the spinal cord, and that the *true centre* is represented by the *sympathetic ganglionic elements of the sacral plexus*. This is the opinion maintained by L. R. Müller as the result of experiments on animals and observations on man.

It is certain, however, that the brain and the whole of the spinal cord, although they do not contain the true, immediate centres of erection and ejaculation, are capable of influencing and determining these acts. For it is known that simple psychic representation in the ambit of the sexual sphere, evoked either by the imagination, or aroused by stimulation of the sense of sight, hearing, and especially the olfactory sense, is sufficient to cause not only erection but also ejaculation; and this occurs independently of any stimulation whatever of the cutis of the penis or the mucosa of the glans. On the other hand, one can easily cause erection experimentally in animals by applying the electric current to the highest segments of the spinal cord, the bulb, the cerebral peduncles, the pons (Budge, Eckhard, 1863). From an old experiment of Segalas (1835), which has been several times confirmed, it is known that puncture, crushing, or destruction by a metallic probe of any small portion whatever of the spinal cord is sufficient to cause erection and ejaculation in a guinea-pig. Numerous are the cases cited in old medico-legal literature of the occurrence of erection of the penis and ejaculation of the semen in men executed by hanging or decapitation. These records were collected, discussed, and confirmed experimentally by Goltz in 1898. Spina, experimenting on guinea-pigs, often obtained the same phenomena by simple transverse section of the spinal cord, and the more surely the lower the section, that is the nearer to the true centre of the reflex.

But, besides the *diffuse excitatory* centres of the reflexes of erection and ejaculation, there are in the brain and cord also *inhibitory centres* for these reflexes. As a proof of this the following fact observed by Goltz is important; it is much more difficult by manipulation of the prepuce to produce erection and ejaculation in the intact dog than in the dog with the lumbosacral portion of the cord separated from the cervico-dorsal, because in the latter case the inhibitory influences emanating from the superior centres are eliminated. If, moreover, in the intact dog one succeeds in obtaining erection in a reflex way, it is easy to make it disappear by electrical stimulation of the skin of a hind-paw, which excites reflexly the supposed cerebral or spinal centres for the *inhibition of erection*.

From the fact easily observable that there may be spermatic ejaculation without erection, even in relatively normal conditions of the functions of the genital apparatus, it may be argued that the central nervous organs concerned in ejaculation are distinct anatomically and functionally from those of erection. Rémy (1886) found alongside the *inferior vena cava* a small ganglion, the excitation of which determined only ejaculation. That there exist distinct centrifugal nerves for the two functions is known; for stimulation of the nerve filaments which supply the vas deferens in rabbits easily arouses expulsive movements, without producing the least erection (M. Loeb, 1866). It is also probable that the centres for the two acts are distinct. If, however, this last proposition is granted, it is necessary to conclude that the two centres are in intimate functional relation with one another, because experience shows that the same peripheral stimuli produce erection when they act with moderate intensity and duration, and ejaculation also when they are stronger and more protracted.

On the complicated sacral nervous flexus of rabbits, cats, and dogs, numerous and minute researches were made by Langley and Anderson (1895-96), with the object of determining by physiological methods the innervation of the genital organs. In man the nervous supply is probably similar to that of the dog.

The *nervus erigens* contains *spinal fibres* proceeding from the first and second sacral roots, and *sympathetic fibres* proceeding from the *hypogastric plexus* and the *mesenteric plexus*. From these sympathetic fibres emanate the nervous filaments which supply the corpora cavernosa.

The *nervus pudendus* arises by four branches proceeding from the first four sacral roots. The *perineal branch* is the motor nerve of the ejaculatory muscles; the *dorsal branch* of the penis is the sensory nerve of the greatest part of this organ. To the *pudendal nerve* also pass sympathetic fibres from the *hypogastric plexus*.

The *nervus erigens*, as well as the *nervus pudendus*, contains numerous vaso-constrictor and vaso-dilator fibres; the first are

most numerous in the *nervus pudendus*, the second in the *nervus erigens*, as the experiments of François-Franck previously mentioned demonstrate.

The *nervus erigens* is normally in a state of *tonic stimulation*. For after it is cut, the vessels of the corpora cavernosa contract, and less blood flows from an incision in them than before the division of the nerve.

Spina has demonstrated in guinea-pigs that inhibition of erection is the result of stimulation of the vaso-constrictor nerves.

VII. That the activity of the male sexual apparatus exercises a great influence on the other organs, and on the organism as a whole, may be affirmed on the basis of the reliable observations and experiments of which a summary is now given.

Of the greatest importance in this respect are the well-known effects of *castration* in animals or man. In domestic animals castration is practised with the object of making domestication and fattening easier in stallions, bulls, rams, and cocks. On men, in whom the ablation or artificial atrophy of the testicles is known as *emasculatio*, it is practised on religious or moral grounds, as in the sect of the *Skoptzy* and amongst the *Gallas*, or with the object of providing custodians for the harems of Mussulmans, or soprano voices for the choirs of the great Christian churches, as was done during the whole of the eighteenth century, or finally for surgical reasons.

When emasculation is performed on boys before puberty it causes failure in the development of the so-called *secondary sexual characteristics*: the bodily conformation, appearance, and temperament of those castrated approach those of the female sex; the skin becomes paler and smoother, the subcutaneous layer of fat more abundant, the growth of hair on the face deficient; the development of the larynx is arrested at about one-third the usual size, and owing to this is produced the soprano or contralto voice common in the female sex; the thoracic curvature diminishes, the pelvis becomes larger, the bones of the limbs lengthen noticeably; the muscular and nervous systems assume a less degree of tonicity; and the psychical character becomes softer, more docile, less impulsive and energetic.

In the adult man castration produces no such conspicuous change. The secondary sexual characteristics, being already developed, persist; the hair, however, falls out, the beard becomes thin, the skin becomes clear and pale, the mammae are accentuated, the thighs and the hips increase in size, and the voice becomes weaker; the sexual feelings are blunted in many cases, in others they persist, at least for some time; now and then sexual inversion manifests itself (the so-called *uranism*); intellectual acumen may remain, of which we have examples in Narses, Origen, and Abelard, but more often those castrated at mature

age become psycho-asthenic, melancholic, and paranoic. In these effects of emasculation on the whole organism one has physiological proof that the determinants of the *secondary male characteristics* are not contained in the sexual organism arising from the germ, but depend on the development of the testicles; for when these are removed during childhood, those characteristics do not develop. The testicles, therefore, exercise independently of their sexual function, which during puberty is accompanied by considerable somatic and psychic phenomena, a most important trophic influence which extends to almost all the organs and tissues of the economy. This correlation of the genital organs with the nutrition and development of the other tissues of the entire organism opens a large field of work to which, up to recent times, physiological research had not been directed.

To account for this correlation, the view which almost exclusively prevailed in the past was that the testicles during the whole time of their full functional activity exercised—by means of their centripetal nerves—a *continuous tonic action*, which was transmitted by the sympathetic through the sacral plexus to the cerebro-spinal nervous system, and thus produced *reflex trophic effects* more or less diffused over the whole organism. This opinion was maintained by the most distinguished physiologists, including Pflüger, who were inclined to consider the nervous system as the supreme *centraliser, dominator, and regulator* of all the functions of the organism.

There are not wanting data which may be adduced to support this view. The multiform trophic effects which manifest themselves in consequence of castration, although diffuse, do not occur equally in all the organs, or in all the tissues constituted alike; for instance, it hinders the development of the hairs of the beard, and not those of the head; it arrests the development of the laryngeal cartilages, and not that of the other cartilages. If a stag be castrated bilaterally after he has lost his old horns, he does not develop new horns; if, on the other hand, he is castrated unilaterally, the horn renews itself only on the side not operated on. The horns of the castrated bull become like those of cows; castration of the boar limits the development of the so-called tusks; in the cock, the growth of the comb and spurs. These *localised trophic influences* are very difficult to explain without admitting a nervous influence which is transmitted from the testicles especially to the affected tissues and organs (Samuel).

Many other effects of castration, however, are explained more simply by the theory that the testicles produce, in addition to the *external secretion* destined for the most important function of reproduction, a special *internal secretion* capable of influencing chemically the other tissues. Let us review shortly the facts. A first series of researches upon the presumed *internal secretion*

of the testicles was communicated by Brown-Séquard and his collaborators to the Société de Biologie of Paris between 1891 and 1893. He announced that hypodermic injections of testicular extract methodically repeated not only mitigated neuro-asthenic conditions, but, acting as excitants of the central nervous system, caused the disappearance of the phenomena of *sexual impotence*, even when they are due to old age; restoring the power of erection, seminal formation, and ejaculation.

This announcement much interested the medical profession, amongst whom spread in a short time the practice of injecting testicular juice as a cure for sexual impotence, before the matter could be put on a satisfactory scientific basis. The beneficial effects at first extolled were certainly exaggerated through professional interests, and were due in great part to the effects of suggestion on the patients, for under rigorous experimental control in the laboratory they were not confirmed.

A series of experiments carried out under strict conditions at Graz by Pregl and Zoth are not, however, wanting in importance, and although conducted on man are free from the influence of suggestion. They studied the action of the testicular juice on muscular work both with the ergographic method and with simple levers, and arrived at the conclusion that the injections alone do not increase the capacity for muscular work, but that associated with daily muscular exercises they conduce to a degree of vigour which with exercise alone it does not seem possible to reach. They saw, besides, that this increase in muscular strength persisted long after the injections of testicular juice had ceased.

In harmony with this result is also the fact observed by Hedbom on the isolated heart perfused with blood; the addition of testicular extract strengthened in a striking manner the rhythmical contractions.

We know nothing of the mode of action of the testicular juice in strengthening voluntary movements, but it appears probable that its action is exercised on the central nervous system. The active principle of the extract has not yet been isolated. Its presence in the organised constituents of the testicles may be excluded, for the extract which is used is subjected first to filtration through porcelain, which does not allow the passage of any organised element. When the seminal fluid is slowly dried, there are formed crystals which chemically result from the combination of phosphoric acid with a base, the so-called *spermine*, of which we have had occasion to speak when considering the prostatic secretion, and the chemical formula of which is C_2H_5N . Poehl (1898) sought to attach to spermine all the virtues which had been attributed to testicular juice: he considered it a potent oxygen-carrier, and as such a powerful physiological accelerator and intensifier of exchange of material. The later researches of

Loewy (1907) led to the result that something in common exists between the action of spermine and testicular juice; that it is one of the active principles which exist in the testicular substance, specially as regards its influence on metabolism. But many other observers have not confirmed as constant the effects attributed to spermine by Poehl, and have advised that treatment with testicular substance is not free from after-effects and danger. Salvioni (1902) described a number of unfavourable symptoms produced on the nervous system by injections of testicular juice; restlessness, vomiting, constipation, lowering of arterial pressure, slow coagulability of the blood. Dixon (1901) observed also respiratory and vasomotor disturbances. He attributed these toxic effects to a *nucleohiston* which can be precipitated from the testicular juice by sodium chloride.

The initiative of Brown-Séquard served in any case to recall the attention of physiologists to the already described correlations of the testicles with the other organs. To decide whether they depend on nervous reflexes or on factors of a chemical nature (*hormones*) due to an internal secretion, attempts to transplant the testicles were made some time ago by Hunter, and repeated by Bertholt (1849), Rud. Wagner (1851), and in more recent times by Göbel (1898), Herlitzka (1889), C. Foà (1901), but always with negative results; the grafting or survival of the transplanted organ did not succeed. Positive results, however, were obtained by Lode (1895) and Hanau (1902) in cocks, with the transplantation of only one testicle—under conditions, that is, of incomplete castration. Foges (1902) transplanted with success both testicles in six cocks, and observed that they did not assume the appearance of capons, but preserved the secondary sexual characteristics of the intact cock. When he left a portion of the testicle but did not perform transplantation, he observed that the cocks assumed a type intermediate between the cock and the capon, resembling the first in the plumage and carriage of the tail, the second in the development of the comb and gills. These results are evidence in favour of an internal secretion of the testicles, for these organs were separated by transplantation from their nervous connections.

Another series of experiments carried out by Loewy and Richter on dogs (1899) demonstrated that castration diminishes, after some days, the intensity of the exchange of material as shown by the amounts of oxygen absorbed and carbon dioxide discharged in a given time. This decline increases with time to a certain limit, which then apparently remains constant. A castrated dog was under observation for three years and a half, and the diminution of the respiratory exchange, about 14 per cent of the initial value per kilogramme of weight, was maintained almost unaltered during all that time. The phenomenon is observed

in cases in which the body increases in weight after castration, as well as in those in which there is a decrease. In the last case the total exchange of material undergoes an absolute reduction; in the first, a reduction relative to the body-weight of the animal.

By these depressive effects on metabolism are easily explained some modifications of nutrition which follow castration, such as fattening, and anomalies in the development of the bones.

Fattening is a direct effect of the diminution of the oxidative processes; it is one of the few cases scientifically determined of accumulation of fat of constitutional and not dietetic origin.

The anomalies of development in the osseous system are also

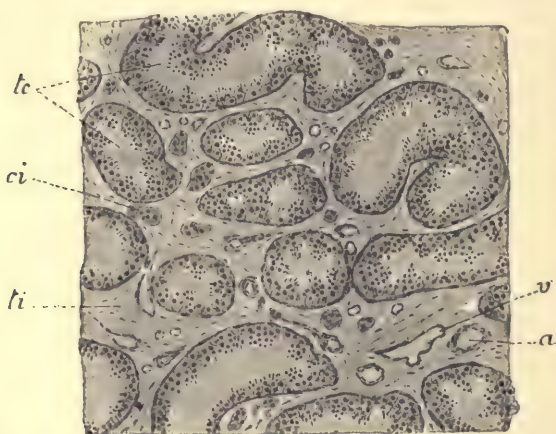


FIG. 41.—Part of a section of a lobule of testicle of man. Magnified 60 diameters. (Sobotta.) *tc*, tubuli contorti; *ti*, interstitial connective tissue; *ci*, group of interstitial cells; *a*, arteriole; *v*, venule.

in great part a consequence of slower metabolism. Sellheim (1898-99) found that they affected not only the bones of the extremities and of the pelvis, but also the bones of the cranium. Lannois and Roy (1902), by means of the Röntgen rays, found that in a castrated man of 27-30 years of age the epiphyseal cartilages were not yet completely ossified. It may be concluded, therefore, that the abnormal growth in height in eunuchs, the greater amplitude of the pelvis, and the conspicuously dolichocephalic skull, depend on the greater slowness in the process of ossification, owing to which the capacity for osseous growth continues longer than usual. These facts were verified by experiments on animals. Poncet (1902) observed in castrated guinea-pigs and calves a greater development of the skeleton than in the intact animals. In bulls, ossification of the cartilages

of the epiphysis takes place after the first year of life; in bullocks, ossification is not complete till the fourth year.

As with the secretions of the thyroid gland and supra-renal capsules, Loewy (1903) has also tried the experiment of feeding young fowl and other animals with testicular substance. But these researches have not yet led to satisfactory and sufficiently definite results. However, from the whole of the data collected it may be affirmed with sufficient certainty that in normal and sexually mature individuals the administration of testicular tissue is generally without effect; but in those sexually immature it accelerates the appearance of the secondary sexual characteristics and arrests prematurely osseous development; nor is it without effect on castrated animals—for example, young

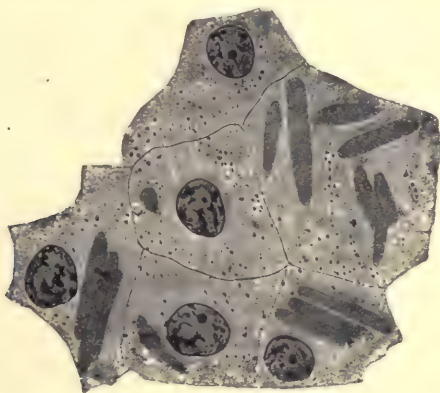


FIG. 42.—Interstitial cells of testicle of man, with Reinke's crystals. Magnified 300 diameters. (Prenant.)

capons—in which it serves to prevent and correct the consequences of castration, so far as it has influence on the organism as a whole; in these cases it distinctly improves the development of the comb and gills, and brings back the processes of ossification to their normal course.

But above all appear to us definite and important the results obtained by Loewy in relation to the exchange of material, the amount of which increases for six to seven days in succession. While awaiting more precise knowledge as to the chemical nature of the specific active substances which exist and accumulate in the testicles, and are capable of producing the effects which we have described, we may ask ourselves whether the presumed *internal secretion* of these organs is produced by the same epithelial elements as those which are responsible for the *external secretion*, that is *spermatogenesis*, or by other specific secretory elements contained in the substance of the testicles. It is known

from the histology of the testicle that in the lobules, besides the *convoluted seminiferous tubules* which represent the chief bulk of the tissue, there are found between the coils, characteristic elements isolated or in groups which are called the *interstitial cells of the testicle*. Besides being found in the interstitial connective tissue of the tubules, these cells are also met with in the fibrous septa, and in the more internal strata of the albuginea (Figs. 41, 42). They are of considerable size (14–21 μ in diameter).

The origin and nature of these interstitial elements is much discussed, but it appears to us undeniable that they are *epithelial cells*, and as such represent, as a whole, a true ductless gland or organ for internal secretion, analogous to the thyroid and parathyroids, and, in respect to total size, certainly more conspicuous than the last. According to the observations of Ancel and Bouin, it appears very probable that the presumed internal secretion of the testicle is formed by these elements, which have specific characters, and have nothing to do with either the seminal cells or the cells of Sertoli.

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CHAPTER V

THE GENERATIVE SYSTEM OF THE FEMALE

SUMMARY.—1. The *ovary* and the *Graafian follicles*, primary and vesicular; *ovulation*, *follicular atresia*, and formation of the *corpora lutea*. 2. The *uterus* and *Fallopian tubes*; the phenomena of female puberty; the periodic phenomena, general and local, of *menstruation*. 3. The relations between ovulation, menstruation, and the variations of the functional tone of the whole organism. 4. The female copulatory organs and their functions during *coitus*. 5. The mechanism of the *impregnation of the ovum*. 6. The phenomena of *maturation*, *fertilisation* of the ovum, and their physiological significance. 7. The fertilised ovum as the *germ of the future organism*. 8. The influence of the ovary on the whole organism, deduced specially from the effects of spaying. Bibliography.

I. THE sexual apparatus of woman is not less complex than that of man. The genital organ in the strict sense is represented by the ovary, which forms the ova, as the testicle produces the spermatozoa; the organs for sexual intercourse, and the expulsion of the foetus are represented by the vulva, or external genital parts, and the vagina; the organs in which occur fertilisation of the ovum and the development of the product of conception are represented by the oviducts or Fallopian tubes and the uterus or womb respectively (Fig. 43).

The *ovaries* are very small at birth, but develop remarkably at the time of puberty; they continue to grow up to mature age; begin to diminish at the critical epoch or menopause, and reach an extreme degree of atrophy in old age. In the adult woman they are 3 to 5 cms. long, 1.5 to 3 wide, and 0.50 to 1.50 thick. They weigh 6 to 8 grms. (Waldeyer). They are of an oval shape, flattened like an almond, with a moderate consistence which increases with age, and a dull reddish-grey colour; in children they have a smooth and regular surface, which from puberty onwards always becomes more irregular owing to the effect, as we shall see, of ovulation or the periodical appearance of the follicles (Fig. 44).

In a section of the ovary may be distinguished a *medullary* or *vascular* substance and a *cortical* or *parenchymatous*. The first forms the central part of the organ, and consists of numerous vessels, nerves, and interposed connective tissue, with elastic and

smooth muscular fibres; the second is a fine lamina (1 to 3 mm. thick) placed at the periphery of the organ, the hilus excepted where the vessels enter; this constitutes, with its *ovarian epithelium*, the essential part of the organ. It is characterised by the presence of the so-called *ovarian follicles*, which contain the *ova*; between the follicles is interposed the *cortical stroma*, formed of connective tissue. The *ovarian follicles* are very numerous at birth and in the first years of life; towards the

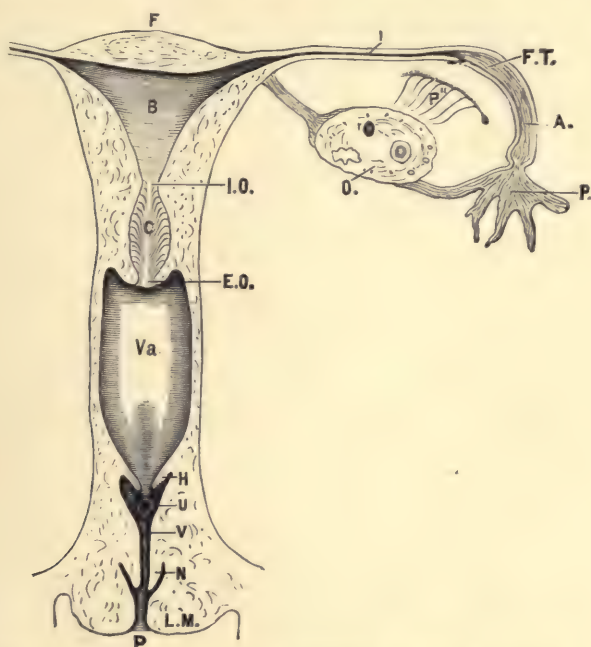


FIG. 43.—Diagram of the female genital organs. (Modified after Henle.) O, ovary; P, epoophoron; F.T., Fallopian tube; P', infundibulum; A, ampulla, and I, isthmus of tube; F, fundus of uterus; B, cavity of body of uterus; C, cavity of cervix of uterus; I.O., internal orifice, and E.O., external orifice of uterus; Va, vagina; H, hymen; U, external orifice of urethra; V, vestibule of vagina; N, labia minora; L.M., labia majora; P, rima pudendi.

period of puberty they diminish in number, and the decrease continues with age. According to Waldeyer (1870), 100,000 to 400,000 ova would be found in the two ovaries of a newly born infant, whereas at the beginning of complete sexual maturity they would be reduced to 30-40,000. A few years after the menopause, follicles are no longer found in the ovary (Figs. 45 and 46). According to Waldeyer's theory, which is most widely spread and generally accepted, the follicles form and multiply in the ovary only during the period of intra-uterine life by a downgrowth of the ovarian epithelium in the form of

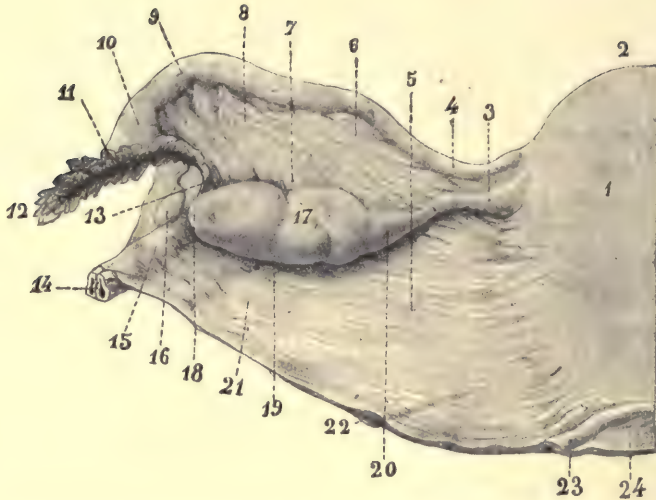


FIG. 44.—Uterus, Fallopian tube and ovary, of left side seen from the posterior surface. (Douglas.) 1, uterus, left half, from intestinal surface; 2, fundus of uterus; 3, ligamentum proprium of ovary; 4, isthmus of Fallopian tube; 5, mesometrium; 6, mesosalphynx; 7, mesovarium; 8, epoophoron; 9, ampulla of the tube; 10, infundibulum of the tube; 11, abdominal orifice of the tube; 12, fimbriae of the tube; 13, ovarian fimbria; 14, ovarian artery and vein; 15, suspensory ligament of the ovary; 16, vesicular appendix (of Morgagni); 17, ovary, median surface; 18, its tubar extremity; 19, its free border; 20, its uterine extremity; 21, broad ligament of the uterus; 22, ureter; 23, recto-uterine fold; 24, recto-uterine cavity.

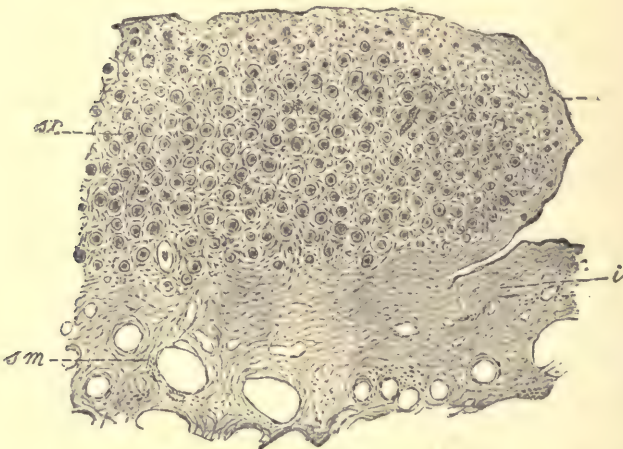


FIG. 45.—Ovary of seven months' foetus. From a section perpendicular to the axis of the organ, through the hilus. A little enlarged. (Chiarugi.) *c*, follicular epithelium, in parts detached; *sc*, cortical substance crowded with primary ovarian follicles; *sm*, medullary substance with numerous blood-vessels; *h*, hilus of ovary.

tubes or cords, first described by Pflüger (Fig. 47). Their greatest number is at the time of birth; from this time to the meno-

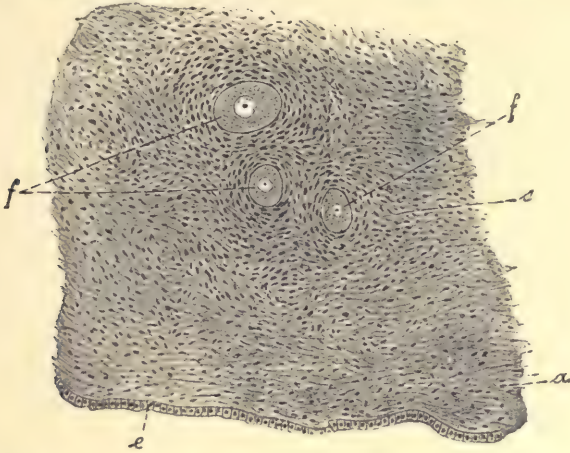


FIG. 46.—Ovary of adult woman. Section through the superficial part of cortical substance. Highly magnified. (Chiarugi.) *e*, ovarian or germinal epithelium; *f*, primary ovarian follicles; *s*, cortical stroma; *a*, albuginea.

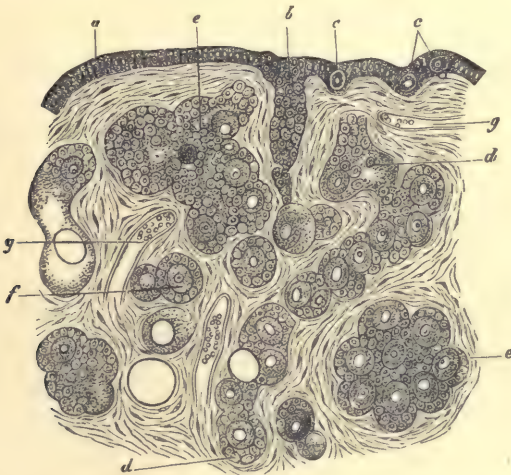


FIG. 47.—Section of ovary of new-born infant. Much magnified. (Waldeyer.) *a*, germinal epithelium which is growing inwards at *b*, to form an egg-tube of Pflüger; *c*, *e*, ovocytes in the germinal epithelium; *d*, *d*, tubes of Pflüger which are resolving themselves into groups or cell-nests; *e*, *e*, cell-nests, very voluminous, with several ovocytes surrounded by follicular cells; *f*, primary Graafian follicle; *g*, *g*, blood-vessels.

pause there is no formation of new follicles, but a continual and progressive disappearance of them due to degenerative pro-

cesses of which we shall speak presently. The subsequent work, however, of Paladino (1881-94), which was not taken into account by Sellheim (1907) in his recent treatise on the subject,

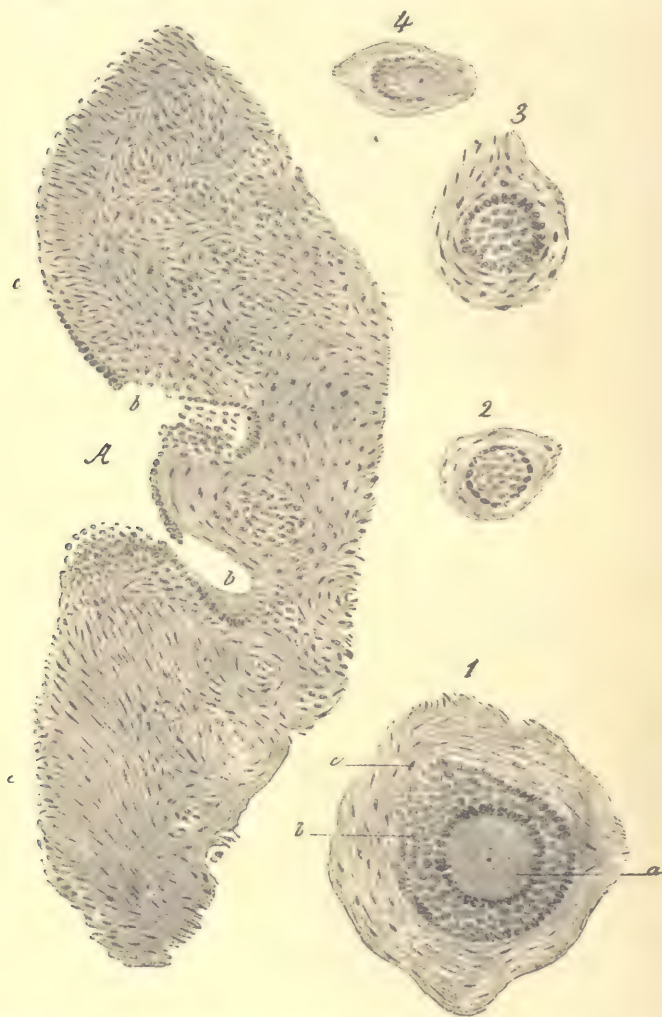


FIG. 48.—Cortical section of ovary of adult woman, and four transverse sections of primary follicles and of ovarian tubes or cords of the same. (After Paladino.) *A*, crater-like depression of ovarian surface or point at which the germinal epithelium is sinking (that in the preparation is in part destroyed); *b, b*, crura of depression or tubular divisions with which it sinks into the stroma; *c, c*, ovarian surface (Oe. 4, ob. 5 of the microscope Koristka); 1, primordial follicle of woman; *a*, ovum with germinal vesicle; *b*, epithelium; *c*, connective tissue. 2, 3, sections of egg-tubes of woman; 4, section of egg-tube with primordial ovum in hyaline degeneration and with epithelium at one side atrophied (primordial follicle defective through degeneration).

led to the conclusion that the ovarian follicles continue to be formed during extra-uterine as during intra-uterine life, and by the same process, with this difference, however, that their periodic

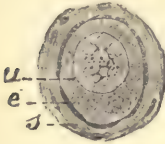


FIG. 49.—Primary ovarian follicle, from ovary of rabbit. Magnified 320 diameters. (Chiarugi.) *u*, ovum with germinal vesicle; *e*, follicular epithelium; *s*, cortical stroma.

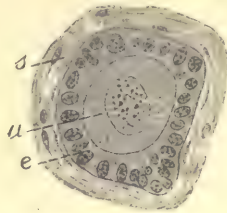


FIG. 50.—Ovarian follicle in growth, from ovary of rabbit. Magnified 320 diameters. (Chiarugi.) *u*, ovum with germinal vesicle; *e*, simple cubical follicular epithelium; *s*, cortical stroma.

destruction, coincident in great part with menstruation, greatly surpasses the new and subsequent formation, which ceases only at the beginning of the menopause. In Fig. 48, taken from Paladino's monograph of 1887, are represented in longitudinal

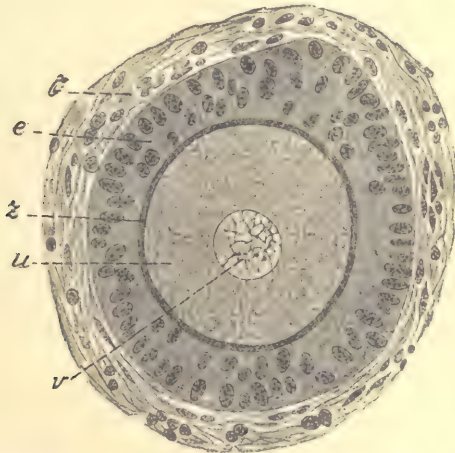


FIG. 51.—Ovarian follicle, from ovary of rabbit, in a more advanced stage of growth than in the preceding figure. Magnified 320 diameters. (Chiarugi.) *u*, ovum; *v*, germinal vesicle; *z*, zona pellucida; *e*, follicular epithelium in several strata; *t*, theca or wall of follicle.

and transverse section the tubes or cords resulting from the sinking of the *germinal epithelium* into the ovary of an adult woman; they are similar to those which are observed in the ovaries of new-born infants. It therefore appears to me undeniable that during the whole of the long period of sexual life there is continued in the woman a double process of destruction

and new formation of the follicles, with a progressive prevalence of the first over the second process, which becomes less than ever at the critical period. The *primary ovarian follicles* are to be distinguished from the *vesicular* or *Graafian*. The first are little spherical bodies which proceed from a stratum of cells called the *follicular epithelium* surrounding a large cell of 35 to 48 μ , which is the ovum with a *cell-nucleus* known as the *germinal vesicle*. The follicles increase progressively in size, and undergo modifications of form in regard to the follicular walls as well as to the ovum (as is seen in Figs. 47, 48, 49, 50). At a given period of their development, at one or more points of the follicular wall,

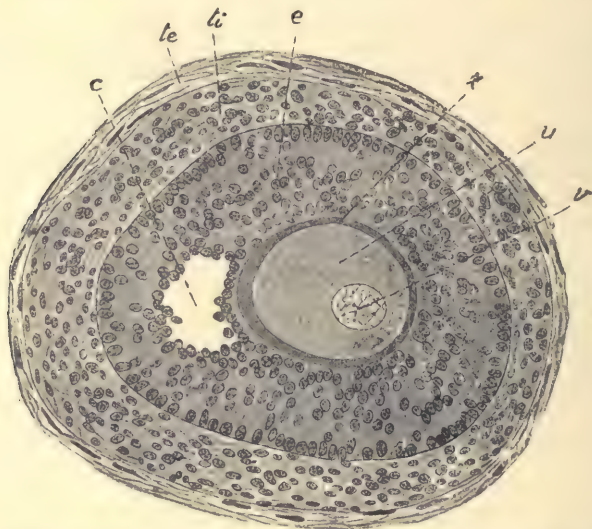


FIG. 52.—Ovarian follicle, from ovary of rabbit, in a more advanced stage of growth than in the preceding figure. Magnified 190 diameters. (Chiarugi.) u, ovum; v, germinal vesicle; z, zona pellucida; e, follicular epithelium; c, first sign of formation of follicular cavity; ti, theca interna; te, theca externa.

is formed a space for the reception of a liquid which increases constantly until the follicle becomes *vesicular*. The *follicular liquid* is yellowish, slightly alkaline, and contains protein substances; it is a product of secretion accompanied by destruction of the epithelial cells of the follicle (Figs. 52, 53). The mature vesicular follicle is known as a *Graafian follicle*. It consists of an investing membrane with two layers, due to modifications undergone by the stroma of the perifollicular connective tissue, called the *theca* or *wall of the follicle*; of the *cumulus oophorus*, formed by a mass of cells of the *stratum granulosum*, with which it is in communication at a peripheral point, situated generally towards the deep pole of the follicle; of the *ovum* (contained within

the *cumulus*), on the surface of which has formed a cell-membrane $20\ \mu$ thick, hyaline, transparent, and called the *zona pellucida* (Fig. 54). In proportion as the *vesicular* or *Graafian follicle* increases in size and matures, it always comes nearer to the surface of the ovary, and ultimately projects. In the centre of this prominence the follicular wall becomes thin; the perfollicular theca disappears, the vessels which supply it atrophy almost completely, and thus is produced a pale translucent spot which is called the *stigma*. At the part corresponding with the

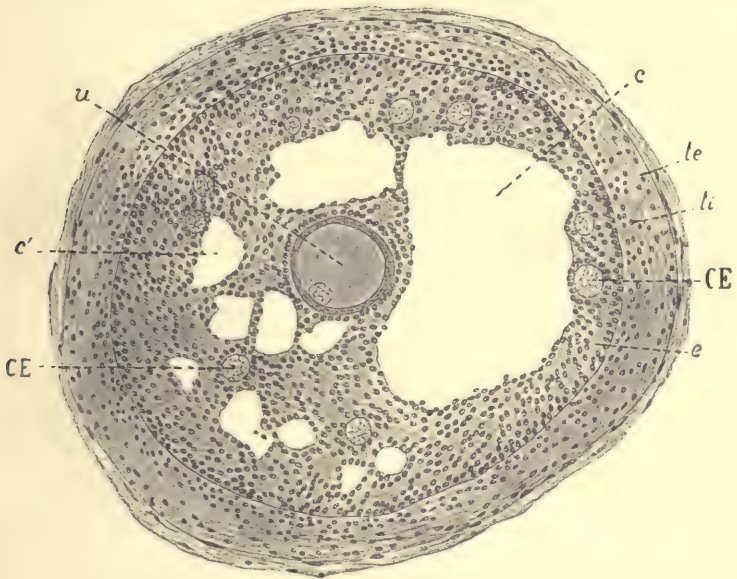


FIG. 53.—Ovarian follicle in growth, in act of becoming a vesicular follicle, from ovary of rabbit. Magnified 76 diameters. (Chiarugi.) *u*, ovum with germinal vesicle and zona pellucida; *e*, follicular epithelium; *CE*, bodies of Call and Exner; *c*, principal follicular cavity; *c'*, small follicular cavities which have not yet united with the principal; *ti*, theca interna; *te*, theca externa.

stigma occurs the rupture of the Graafian follicle and the escape of the ovum surrounded by the cells of the cumulus oophorus, which form the so-called *corona radiata*. The growth of the ovum is shown by the difference in size which it presents at the beginning, when it is contained in the primary follicle, and at the end of its maturity, when it is driven out by the bursting of the folliculus vesiculosus and is provided with the *zona pellucida*. In the first stage it has a diameter of about $25\ \mu$, in the last stage it measures $200\ \mu$ (the *zona pellucida* about $10\ \mu$, the germinal vesicle $50\ \mu$, and the macula germinativa $5\ \mu$). The mature ovum is about eight times larger than the primordial.

We shall see in due course what other changes it has to undergo to become capable of fertilisation.

In the protoplasm of the ovum of the rabbit, besides the cavities containing the liquid material for nutrition, there exist—according to the researches of A. Russo (1907)—globules of a lipid nature belonging to the group of *lecithins*. These globules are formed in the ovum rather advanced in development, that is,

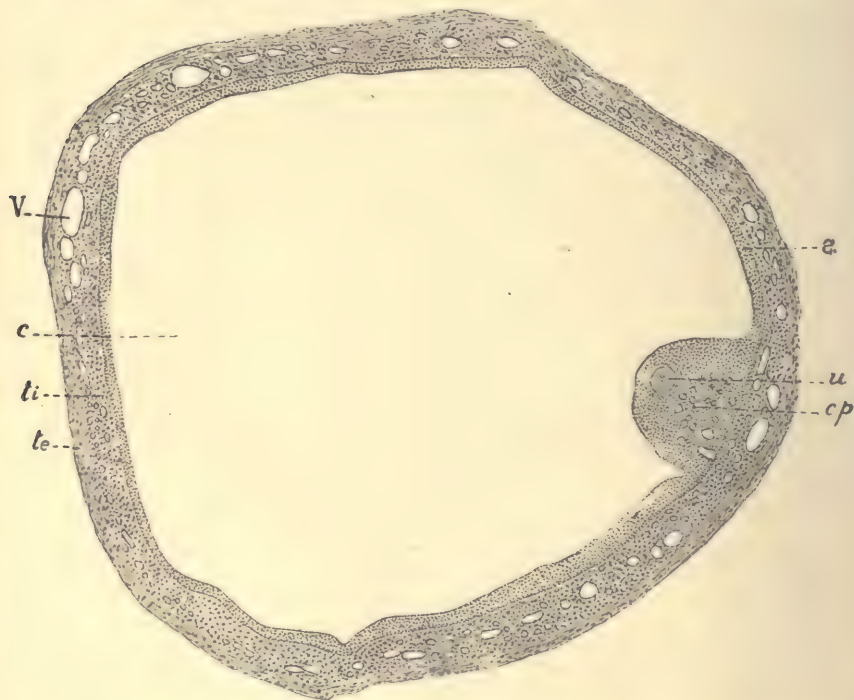


FIG. 54.—Vesicular or Graafian follicle of woman. Magnified 34 diameters. (Chiarugi.) *u*, ovum; *cp*, cumulus oophorus; the little cavities which may be noticed represent penetrating vessels from the theca interna; *e*, follicular epithelium (stratum granulosum); *c*, cavity of follicle; *ti*, theca interna; *te*, theca externa; *V*, vessels.

an ovum with a much stratified follicle, in which is beginning to form the follicular cavity with its *liquor folliculi*. In the less-developed ova are observed only very minute granules disposed in chain-like strings, and from their micro-chemical reactions also lipid. Russo has found that these granules, as well as the globules, can be produced experimentally by injecting lecithin under the skin or into the peritoneal cavity. S. Comes, a pupil of Russo, has confirmed these results in the ova of the cat, at different times of its physiological activity, at the period of heat,

during gravidity, and also at times removed from the period of sexual excitement.

In rabbits, according to Russo, besides the ova with the globules of lecithin, there are ova which are without them, and contain in their place crystals of fatty acids. The latter are more easily subject to degeneration. Considering the statistics collected by Bodio for man, which show that the still-born are for the greater part of the male sex, Russo audaciously draws the conclusion that the ova without globules of lecithin are *destined to produce males*, whilst the ova provided with them *produce females*! Without denying that the said granules have an importance for the development of the germ, we must, however, insist that we are not yet in a position to define it.

The whole process of maturing and rupture of the Graafian follicle, with the consecutive escape of the ovum, is conveniently called *ovulation*. This happens periodically at every lunar month, that is every four weeks, usually before the *menstrual bleeding* begins, as we shall describe in more detail later on. Ovulation continues through the whole duration of the generative activity or capacity of woman; it begins with puberty or sexual maturity, and does not cease until the critical age or menopause. But of the immense number of *ovarian follicles* which are found in the ovary of the foetus, or are formed subsequently, only a very small part pass through all the phases of development and reach maturity. The greater part of them disappear by a physiological process of obliteration or *follicular atresia*, which commences at birth and continues with varying intensity until the cessation of the generative activity of the woman. Atresia affects specially the primary follicles, but may also attack the follicles more or less advanced in development. Both in the first and in the second, the process begins with degeneration of the ovum, which manifests itself either by simple atrophy or by *chromatolysis* of the germinal vesicle; the chromatin is reduced to granules, the nuclear membrane is destroyed, and the contents dissolve in the body of the cell, which at the same time undergoes fatty degeneration. The follicular epithelia are also destroyed, and their remains and the vesicular liquid, if it is already formed, are absorbed. In this process a part is taken also by the leucocytes, which, penetrating into the follicles and even into the ova, exercise their phagocytic action.

As a final result of this process of atrophy of the follicles, the hypertrophied interfollicular connective tissue takes the place of the follicles destroyed. The large follicles which were nearest to maturity do not, however, as a consequence of these degenerative processes disappear altogether, but are transformed into little cysts devoid of epithelial lining (Slaviansky, 1874; Schottländer, 1891-93; Wandeler, 1898).

As the result of the bursting of the Graafian follicle there almost always occurs a haemorrhage, which is generally slight, and is due to laceration of the vessels of the follicular theca; and the blood collects and coagulates in the cavity of the follicle. Later, through the activity of the stratum granulosum of the burst follicle, there is produced in its place a special organ, called the *corpus luteum*. Owing to the expulsion of the contents of the follicle, and the retraction of the follicular theca, the stratum granulosum is reduced to a crinkled lamina which surrounds the coagulated blood. This lamina increases constantly in thickness, occupying a greater and greater part of the cavity of the old

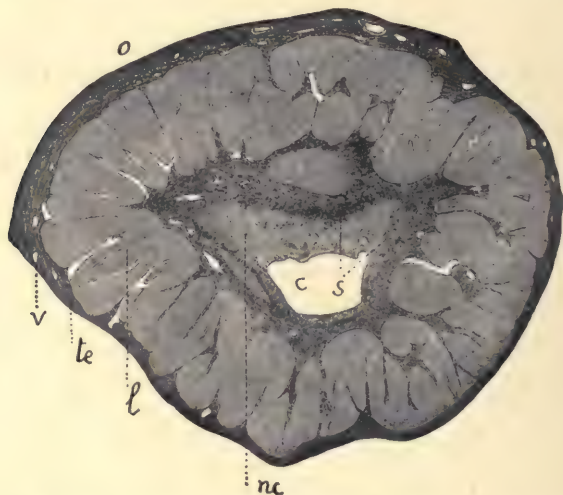


FIG. 55.—Section through a corpus luteum of the ovary of a woman who died at the fifth lunar month of pregnancy. Magnified 6 diameters approx. (Kölliker.) *nc*, central connective tissue; *l*, stratum of lutein cells; *o*, surface of ovary; *s*, remains of extravasated blood and hyaline masses; *v*, blood-vessel; *c*, remains of central cavity; *te*, external tunic of follicle.

follicle, whilst the coagulum is condensed and in part reabsorbed. In this manner is formed a more or less spherical, yellowish-grey body, the *corpus luteum* (Fig. 55). It attains a greater size than that which the follicle had (1 to 2.2 cm.). The mass of the fully developed corpus luteum is formed of *lutein cells*, so called because they contain granules of *lutein*, which is a lipochrome soluble in alcohol and ether, and like the fats staining black with osmic acid (Fig. 56). From the follicular theca penetrate towards the stratum of lutein cells numerous connective-tissue fibres, which enclose the lutein cells in a delicate meshwork. The residual parts of the extravasated blood are recognisable as hyaline masses in which Virchow discovered the *haematoidin* crystals.

After the twelfth day from the bursting of the follicle, if

fertilisation has not taken place, or after the fifth to sixth month if pregnancy followed, the development of the corpus luteum ceases and the involution begins, in the first case (*corpus luteum spurium*) rapidly, in the second (*corpus luteum verum*) much more slowly, so that it is recognisable even at the time of parturition.

The retrogression of the corpus luteum manifests itself by a diminution in size and a progressive increase of consistence, by which it is converted into a little *fibrous nodule*, or into a body of hyaline appearance, which is called the *corpus fibrosum albicans* (Fig. 57). This occurs owing to the degeneration and reabsorption of the lutein cells, and the simultaneous organisation of the central gelatinous tissue into dense fibrous tissue. Finally, the *simple fibrous nodules* and the *corpora fibrosa albicantia* gradually disappear owing to hyaline degeneration, and there remains of them

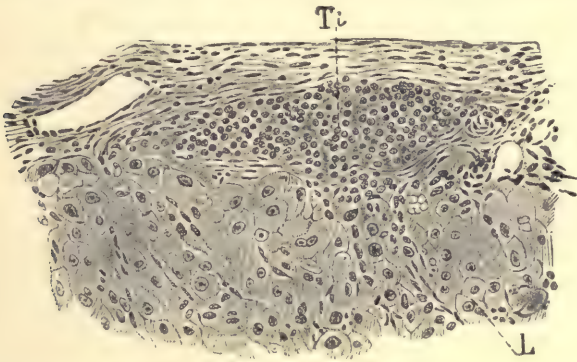


FIG. 56.—Cortical part of a corpus luteum of woman in fifth week of pregnancy. Highly magnified. (Hans Rabl.) L, lutein cells; Ti, theca interna with hypertrophic cells.

only a cicatricial contraction by which—as we have said—the surface of the ovary is made always more irregular with age.

II. With *ovulation* is initiated in woman the period of *puberty*, which in our temperate climate occurs at 13 to 15 years of age. It manifests itself by a new phenomenon, the sanguineous flow from the vulva, which is called *menstruation* (*catamenial flux* or monthly periods); we shall examine this process and its internal causes. Puberty is shown also by a number of metamorphoses which affect the development and the functions of the entire organism. The larynx develops and the voice loses its sharpest notes, but in compensation acquires greater intensity; the circumference of the thorax increases, and the pelvis enlarges; the subcutaneous layer of adipose tissue becomes thicker; the nipples protrude; hairs appear on the pudendum and in the axillae; the psychical character is modified, becoming more reserved and modest; in fact, the whole generative system, external and

internal, becomes developed in relation with the new functions which are carried on by the ovaries and uterus.

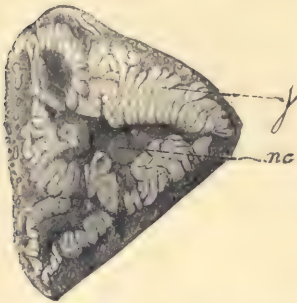


FIG. 57.—Corpus albicans of woman. (Hans Rabl.) *nc*, central connective tissue; *j*, fibrous hyaline substance formed in the stratum of lutein cells after their degeneration.

For the proper appreciation of the processes which underlie these new *internal functions* we will remind the reader of the structure of the *uterus*, which is the seat of the menstrual bleeding, and the Fallopian tubes, which provide for the transport of the ovum from the Graafian follicle to the uterus, and are for that reason more properly called *oviducts*.

The uterus is a hollow organ, pyriform, flattened from front to back, with the base upwards, the apex below, to which is conjoined

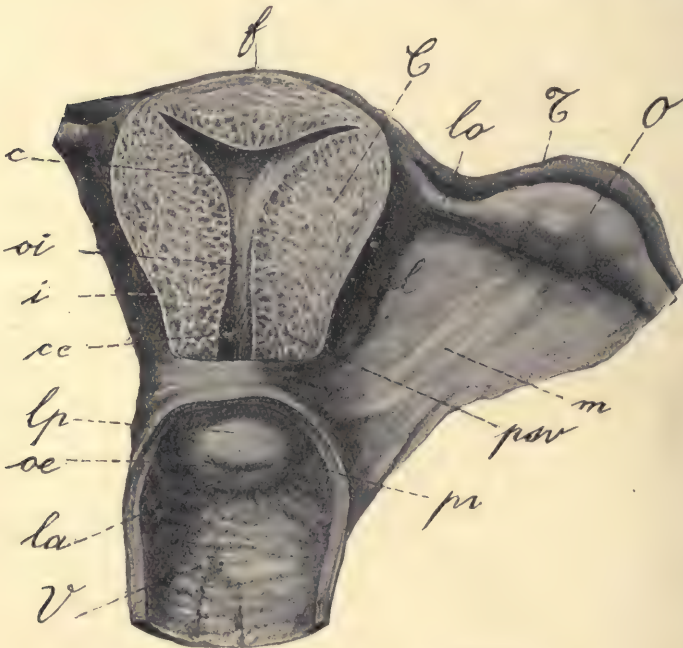


FIG. 58.—The uterus from behind, with initial tract of vagina; together with the ovary, part of the uterine tube and of the broad ligament—right side. The uterus was opened by a frontal incision, except the vaginal portion of the neck which is entire. The ovary with the mesovarium is raised. (Chiarugi.) *c*, body of the neck; *f*, fundus and superior margin; *l*, lateral margin; *c*, cavity of body of uterus; *oi*, internal uterine orifice; *cc*, cervical canal; *oe*, external uterine orifice; *la*, anterior lip; *lp*, posterior lip of orifice; *V*, anterior wall of vagina; *T*, uterine tube; *O*, ovary; *lo*, ligamentum proprium of ovary; *m*, mesometrium.

a cylindrical prolongation called the *cervix* (Fig. 58). It is essentially a *hollow muscular organ* with walls of considerable thickness and firmness, which consist of smooth muscular fibres interwoven in an almost inextricable manner. It is invested externally with a *serous membrane* (*perimetrium*), which differs in no way from the ordinary serous peritoneum (Fig. 59). It is covered internally by a *mucous membrane* (*endometrium*), about 1.5 mm. thick, soft, and covered by a thin layer of viscous fluid of alkaline reaction. The endometrium consists of a simple cylindrical epithelium provided with ciliated epithelium with a movement directed from the fundus of the uterus towards the cervix. The epithelium rests on a *tunica propria*, which has the structure of *lymphoid tissue*, in the meshes of which are collected lymphocytes, especially abundant around the little blood and lymphatic vessels with which the mucosa is richly provided. The uterine mucous membrane is rich in *tubular glands*, simple or bifid at the extremity (Fig. 60), covered by an epithelium similar to that of the surface and resting on a basement membrane.

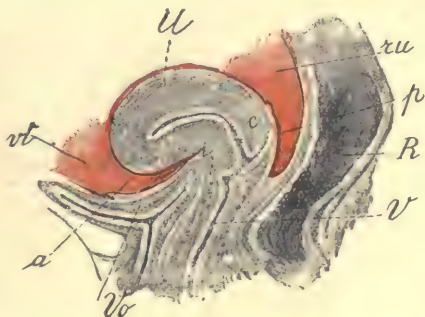


FIG. 59.—Diagram showing relations of uterus, part of vagina, urinary bladder, and rectum. The peritoneum is in red. (Chiarugi.) U, body of uterus; V, vagina; t, isthmus; c, cervix of uterus; Vo, bladder; R, rectum; vt, vesico-uterine peritoneal cavity; vt, transverse vesicular fold; p, bottom of recto-uterine peritoneal cavity; ru, recto-uterine fold.

The mucosa of the uterine neck is thicker, more resistant, and paler than that of the body of the uterus. Its surface is uneven, and presents oblique ridges (*Plicae palmatae*).

It possesses a cylindrical ciliated epithelium with cells thinner and longer than those of the body of the uterus, a firmer tunica propria due to more numerous connective-tissue fibres, but it is poorer in lymphocytes, and contains only a few glands. These secrete an *alkaline*, very viscid mucus, which fills the cervical canal, and often makes its appearance at the external orifice of the cervix.

The internal cavity of the uterus varies in form in the *virgin*, the *nullipara*, and the *multipara*, as may be seen at a glance in Fig. 61. The anterior and posterior walls which circumscribe the uterus are in contact, or rather they are separated by a thin layer of mucus, hence the cavity of the uterus may almost be said to be only potential. The cavity of the cervix, however, is always distended with mucus, even in virgins.

The *oviducts* or *uterine tubes* open medially into the uterine cavity, and laterally into the peritoneal cavity (Fig. 62). The

uterine mouth, or *ostium uterinum*, of the tube is continuous with its *uterine portion*, which is 10 mm. long, and with the *isthmus*, which is 3 to 4 cm. long, and has a calibre of 3 to 4 mm. Then comes the *ampulla*, which is the principal segment of the oviduct, 7 to 8 cm. long, with an average diameter of 7 mm.; it has thin walls easily distended and compressed, and an undulatory course. Lastly, the *abdominal opening*, or *ostium abdominale*, of the tube has a diameter of 2 to 3 mm., and is found in the deepest part of the *infundibulum*, which dilates to a funnel shape, and at its termination is cut into little tongues called *fimbriae*. The uterine



FIG. 60.—Section of the mucous membrane of the uterus of young nullipara. Magnified 150 diameters. (Sabotta.) *ep*, investing epithelium; *gl*, uterine glands, variously cut (obliquely or transversely, according to their axes); *gl'*, uterine glands cut along their walls; *tp*, tunica propria of the mucosa; *M*, thin stratum belonging to tunica muscularis.

tube is movable or displaceable, specially in its ampullary and infundibular tracts, and resumes its original position with great facility when the cause which has occasioned the displacement has ceased to act. The internal surface of the uterine tube is marked by numerous longitudinal folds, variously developed in the different tracts, as may be seen in Figs. 63 and 64. Its walls consist chiefly of two strong layers of smooth muscular fibres—one *internal*, with a *circular* course; the other *external*, with a *longitudinal* course. These muscular layers are enveloped on the outside by a *tunica adventitia* of connective tissue and a peritoneal *serous tunic*: they are furnished on the inside with a *tunica mucosa* formed of cylindrical ciliated epithelium, with a movement of the cilia directed

towards the uterus; it is rich in blood-vessels and lymphatics, and devoid of glands.

Like ovulation, menstruation is also a periodic phenomenon

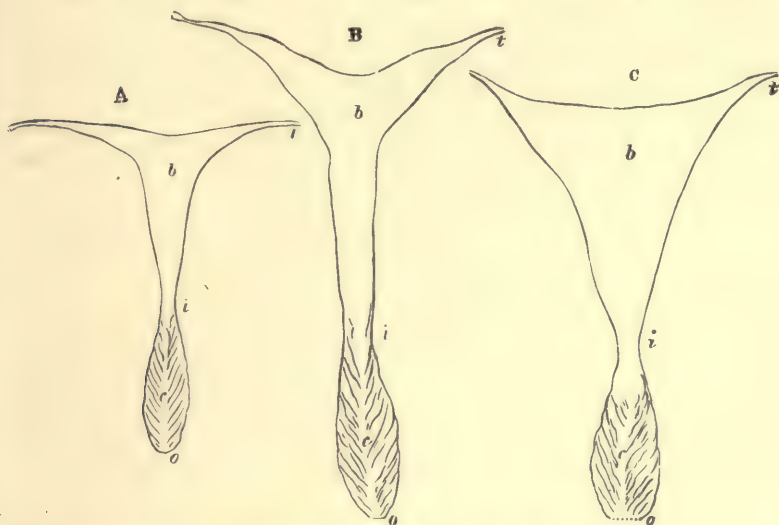


FIG. 61.—Form of uterine cavity at different stages. Somewhat reduced in size. (F. Guyon.) A, of virgin of 17 years of age; B, of woman of 42 years of age, nullipara; C, of woman of 35 years of age who has borne children. *b*, cavity of body; *c*, cavity of cervix; the palmate folds are seen; *i*, isthmus and internal uterine orifice; *o*, external uterine orifice; *t*, superior external angle of uterine cavity and uterine orifice of tube.

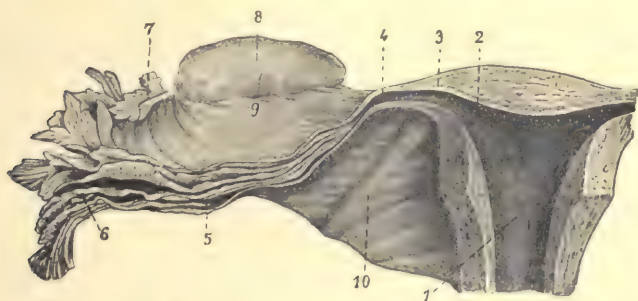


FIG. 62.—Right uterine tube, open throughout its length, with uterus and ovary, from a multipara. The tube has been reduced, and the preparation is seen from the front. (Richard.) 1, uterine cavity; 2, uterine orifice of tube; 3, uterine wall; 4, isthmus; 5, ampulla, and 6, infundibulum of tube with folds; 7, ovarian fimbria; 8, ovary; 9, hilus of ovary; 10, round ligament.

which normally recurs every lunar month (twenty-eight days). Most women, according to Strahl, menstruate at the first quarter of the moon, very few at the time of full moon or new moon. The phenomenon of the menstrual flux is observed also in the mammals,

particularly in apes, mares, and cows; in the bitch it is represented, according to my observations, by a slight mucous secretion, scarcely sanguineous. But in mammals in general the menstrual period has its analogue in the period of *rutting*, or "heat," as the

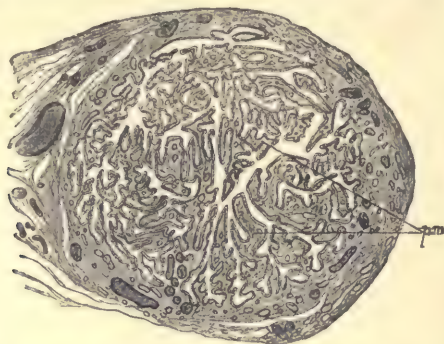


FIG. 63.—Transverse section of uterine tube near its abdominal orifice. A little enlarged. (Orthmann.) *pm*, folds of the mucosa, numerous and much ramified. The muscular tunic is very thin and rich in vessels.

veterinarians say; this observation was made by Aristotle, and repeated by Bischoff in 1844.

Menstruation is preceded and accompanied in woman by a congestive state of all the sexual apparatus, specially the uterus,

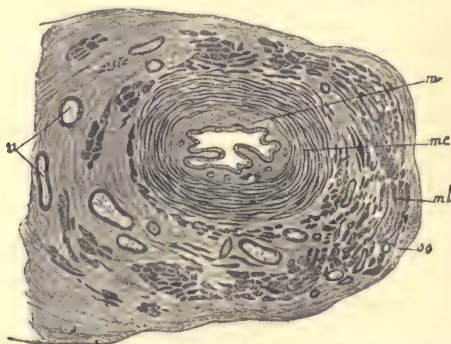


FIG. 64.—Transverse section of uterine tube near its uterine orifice. A little enlarged. (Orthmann.) *m*, tunica mucosa; *mc*, circular stratum of muscular tunic; *ml*, longitudinal stratum of muscular tunic; *ss*, subserous coat; *v*, blood-vessels.

and we shall consider later the different phases, the varied intensity, and the haemorrhagic effects of the process. This congestive and haemorrhagic state is accompanied by a number of abnormal phenomena, both subjective and objective, which involve almost all the vital processes in woman. Heaviness in the loins, a sense of tension, occasionally of pain in the uterus and ovaries

which is increased by pressure, tiredness of the legs, general sense of malaise, disturbances of the gastro-intestinal functions, of defaecation and urination, transient sensations of heat accompanied by sudden reddening and successive pallor of the face. This total of symptoms, which in great part are within the bounds of physiological phenomena, the Ancients called *molimina menstrualia*.

With advanced methods of inquiry there have been brought into prominence by Goldmann, Reinl, V. Ott, and by Bossi other objective phenomena connected with the period which precedes, coincides with, and follows menstruation. The frequency of the pulse, the arterial pressure, the muscular strength, the pulmonary capacity, the inspiratory and expiratory power, the reaction-time of the patellar reflexes, increase in the five or six days which precede menstruation and diminish immediately before and during the five or six days of menstrual flow, finally returning gradually to the normal in the successive days. On the other hand, the sensitiveness and excitability of the nervous system in general, the radiation of heat, the formation and elimination of urea in the urine increase somewhat in coincidence with the most intense phase of the menstrual period (Schrader); but the gaseous respiratory exchange does not show any sensible variation with the similar period (Zuntz). With the increase of the general functional tone of the pre-menstrual period is accentuated in some women the tendency to sexual intercourse which marks the period of rutting in animals.

The essential phenomena of menstruation consist in the changes which the *uterine mucosa* undergoes. It begins to become tumefied through hyperaemia of its vessels, and hyperplasia of the epithelium, and thus its thickness increases from 2-3 mm. to 6-7 mm. (Leopold). This stage of the process is usually called *pre-menstrual tumefaction*, and is most marked in the parenchyma of the ovary and the body of the uterus; in a less degree participate also the cervix, the mucosa of the Fallopian tubes, the external genitals, and also the mammary glands, in which are noticed, not infrequently, in addition to a subjective sense of tension, a slight swelling and indications of secretion.

The stage of tumefaction passes to that of escape of red blood corpuscles, either by diapedesis or by rupture of the capillaries in the interstices of the mucous membrane, with a collection of blood, irregularly disseminated in the sub-epithelial lacunary spaces (haematoma of Gebhard). The formation of these haematomata causes the rupture and detachment of the epithelium and the flow of blood into the uterine cavity, from which it trickles slowly through the cervix and the external genitals. The exfoliation of the superficial epithelium and the uterine glands continues, even increases, after the haemorrhage has ceased; it

is mostly in the form of detritus, but occasionally—especially in virgins—there has been observed detachment of the epithelium in coherent form as a fine membrane to which is given the name of *catamenial decidua*. With the post-haemorrhagic detachment of the epithelium just described harmonises the fact that the menstrual flow during the first three days presents the colour of venous blood, and in the days following always becomes paler and less in quantity.

The amount of blood which is lost during menstruation differs much in each individual (from 100 to 300 or from 30 to 40 grms.), and is naturally in proportion to the extent and intensity of the bleeding from the mucosa, and the consequent degeneration and detachment of tissue. The haemorrhage is confined to the mucosa of the body of the uterus; the oviduct, the cervix of the uterus, and the external genitals do not participate in the process, except by a slight increase in the secretion of mucus.

After the *haemorrhagic* and *degenerative* stage follows the stage of *regeneration* of the uterine mucous membrane. The remaining infiltrated blood is reabsorbed; the exfoliated epithelium renews itself by karyokinesis, and after about fourteen days from the beginning of the menstrual flow the mucosa is restored to its normal condition.

If one takes into account the fact that menstruation recurs normally every twenty-eight days, and is preceded by the stage of tumefaction of the mucosa which lasts from four to five days, it may be concluded that the *resting period* of the uterine mucosa which intervenes between two successive menstruations is not more than ten days. From what has been said it is easy to foresee that the menstrual flow cannot be constituted of pure blood, but of blood mixed with mucus and more or less degenerate cells of the uterine and vaginal epithelium, which in fact are observed and recognised easily with the microscope, together with erythrocytes and leucocytes. Menstrual blood, on account of the alkaline mucus with which it is mixed, does not readily coagulate, and has a more or less unpleasant odour, not adapted certainly to promote venereal excitement, but rather to depress it. It may even prove irritant to the mucosa of the glans penis and male urethra, independently of the eventual virulent action of gonococci. However, the opinion largely diffused among the lay public, that menstrual blood has poisonous properties transmissible to the male, is certainly exaggerated. This belief takes its origin from the old theory which considered menstruation as a purification by which the woman each month purged herself of certain poisonous materials accumulated in the blood. From that theory also come the name of *purgatio mensile* given to menstruation and the precept imposed by the Rabbis on the

Hebrews, not to practise coitus until twelve days from the beginning of menstruation.

III. Modern obstetricians and gynaecologists consider that ovulation coincides with the period of *pre-menstrual tumefaction*, when there is an increase of general functional tone, and a more accentuated tendency to sexual intercourse. Several times during the examination of women accidentally killed, or operated on during the menstrual period, there has been observed in one or other of the ovaries a recently ruptured Graafian follicle. I myself remember having as a student met with such an instance in the body of a young woman at the clinic of Concato. In some women in whom an adequate examination of the ovary is possible, the obstetrician can some days before the beginning of menstruation recognise by digital manipulation a projection in the right or left ovary, of the size of a cherry and painful to pressure; this is certainly due to a mature follicle, ready to burst, for it disappears with menstruation.

According to Strassmann, a *latent period* of one or two days intervenes between the rupture of the mature follicle and menstruation. This time-relation between the escape of the ovum and the beginning of the menstrual flow leads one to admit a causal connection between the phenomena. A series of facts demonstrate that the ovary is the predominant organ, from which start the impulses to all the periodic functions of the female genital apparatus, and to all the modifications of functional tone of the whole organism which accompany them. On the other hand, the functions of the ovary are independent of these local and general effects which they bring about, but which may also be wanting, as is demonstrated by the following facts.

(a) Although ovulation is followed normally by menstruation, there are physiological states (*lactation*) and pathological (*oligaemia*) in which ovulation occurs without being followed by any menstrual flow (*amenorrhoea*).

(b) For the occurrence of menstruation it is not absolutely necessary that there should be rupture of a Graafian follicle; it is sufficient that an ovum in the process of maturation, and before it has arrived at complete development, should perish by chromatolysis of the germinal vesicle in the interior of the follicle; this may happen through abnormal increase of the abdominal pressure around the ovary, however caused, which is capable of preventing the bursting of the follicle (Strassmann). This fact being admitted, we can easily account for the exceptional cases observed by Kölliker, Coste, Leuckhart, and Ritsche of women in whom during abdominal section during the menstrual period no *recent corpus luteum* was seen, although *closed follicles* in the process of maturation, atrophy, or degeneration were observed.

(c) After total extirpation of the uterus periodic ovulation is not suspended (Abel).

(d) Ovulation may persist even after the ovary has been detached from its normal anatomical relations and transplanted in another part of the abdominal cavity (Knauer, Grigorieff, C. Foà, Morris).

In contrast to this independence of the function of the ovary is observed a strict subordination of the periodic function of the uterine mucosa to the presence of the ovary, and to its periodic functional state:

(a) The proliferation, congestion, and haemorrhagic process of the uterine mucosa appear periodically only when the ovary is functioning, that is, is capable of maturing the ovum. In fact, menstruation begins with puberty, when the process of maturation of the ova is initiated, and ceases at the critical epoch (at 45 to 50 years), when the ovary undergoes physiological involution.

(β) After complete spaying the menstrual flow ceases entirely. There are not wanting rare exceptions to this rule (Romiti and others), but it is doubtful whether the case can be considered as one of true menstrual flow, rather than irregular and pathological metrorrhagia (Gusserow).

(γ) Strassmann (1870) carried out a series of experiments on animals, with the object of producing by means of injections an artificial increase of pressure in the parenchyma of the ovary, on which depends the increase of volume of the follicle in the course of maturation. The animal so treated showed in its behaviour, and in the uterine mucosa, the same signs which are observed during ovulation.

These facts demonstrate that the periodic increase in size of the follicles is one of the direct causes of the periodic function of the uterine mucosa.

The periodic variations of functional tone of the entire organism are also an effect of the periodicity of ovulation. They are not, in fact, any longer noticeable after spaying, and after the critical period or menopause. As to the undeniable connection, now admitted by all, between ovulation and menstruation, there exist two principal theories—one formulated by Pflüger (1865) and the other by Löwenhart, Reichert, Gusserow (1874), His (1880), and Sellheim (1907). It is unnecessary to take into account more ancient theories which to-day can only have a simple historical interest. Pflüger considered menstruation as a freshening, in a surgical sense, of the uterine mucosa, necessary in order that the fertilised ovum which arrives there from the oviduct may become adherent, graft itself there and develop, in the same way that it is necessary in plants and in animals to incise or freshen the parts to which it is wished to join the graft. To

account for the periodicity of the process he puts forward a stimulation of the nervous centres by the progressive intumescence and development of the follicle, and a reflex congestion of the uterus and ovary. This congestion gives rise in the uterus to the menstrual hæmorrhage, and in the ovaries to a more rapid increase in size and bursting of the follicle.

The other theory taught by His and by his precursors and successors considers likewise the periodic process of the uterus as directed to prepare for the fertilised ovum a suitable bed for striking root and for development; but holds that this preparation is represented by the *tumefaction and congestion of the uterine mucosa which precedes the hæmorrhage*, and to which is due the formation of the *catamenial decidua*. If the ovum which arrives in the uterus during this stage of the process is not fertilised, it does not attach itself there but is lost through the vaginal canal, and then follow the detachment of the decidual epithelium and the menstrual hæmorrhage. If, on the other hand, the ovum has been fertilised, it inserts itself into the tumefied mucous membrane, which is a bed adapted for its reception and development, and the hæmorrhagic process does not take place. According to this doctrine, then, menstruation is the sign of a missed pregnancy, which would date not from the *last menstruation*, but from the *first which failed to occur*.

To this theory the objection may be raised that it is difficult to understand how the fertilised ovum, directly it has become adherent to the uterus, can exercise an influence so great as to suspend the process in course and prevent the menstrual hæmorrhage. It is known, however, that in some cases, although rare, menstruation may continue even during pregnancy, specially in the first month of gestation. Statistics collected by Hasler (1876) of 248 cases of pregnancy, in which the day of the fruitful coitus was well authenticated, show that conception most frequently (in 86 per cent) takes place within the first ten days from the cessation of menstruation. This is apparently evidence in favour of Pflüger's theory; nevertheless, this is not the theory preferred to-day by obstetricians and gynaecologists, who show little faith in the statistics of Hasler.

IV. The organs of sexual copulation (*coitus*) are represented in woman by the *vagina* and the *vulva* or *pudenda*. They serve also to give exit externally to the periodic menstrual flow, and in parturition to the product of conception.

The vagina is a muscular canal, flattened when in its natural state, from which it follows that when seen in section it presents itself as a transverse fissure which at its extremities divides into two branches so as to form the letter H (Fig. 65). When the vaginal canal is distended, as occurs during copulation, or the introduction of a speculum, it assumes the form of a hollow

cylinder of a size corresponding to that of the extraneous body by which it is distended. The fundus of the vagina is called

the *vaginal fornix*, and is represented by a circular groove with a blind bottom; within this projects the inferior part of the cervix of the uterus with which the vaginal wall is normally in contact. The external vaginal orifice by which the vagina communicates with the deep part of the vulva, is surrounded in virgins by a vaginal fold which is called the *hymen*; it is usually of a semi-lunar form, but is subject to numerous variations and anomalies, which have a notable interest from the point of view of forensic medicine (Fig. 66). In the first sexual relations the hymen is usually lacerated in its free margins with effusion of blood (*defloration*), and after cicatrization is reduced to a number of little projections.

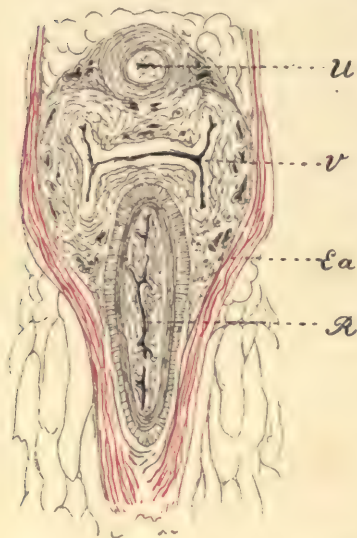


FIG. 65.—Horizontal section of soft parts within lower confines of pelvis. (Henle.)
U, urethra; V, vagina; Ea, levator ani; R, rectum.

During the first parturition, owing to the passage of the foetal head, the lacerations extend to the attached

borders of the hymen, which after cicatricial retraction constitute on the circumference of the vaginal orifice the so-called *carunculæ myrtiformes*.

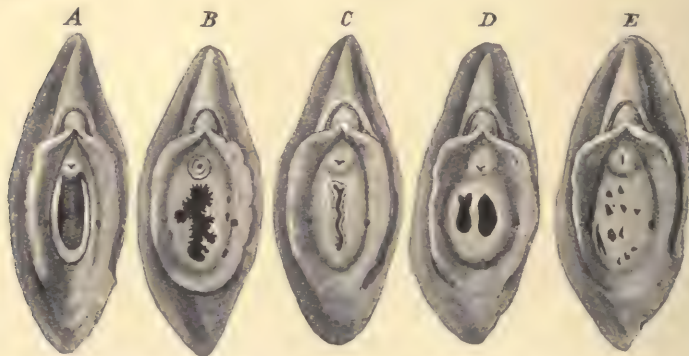


FIG. 66.—Variations of the hymen (Testut). A, hymen semilunaris; B, fimbriatus; C, bilabiatus; D, septiformis; E, cribriformis.

The internal surface of the vagina presents many transverse or oblique rugae caused by the presence in the vaginal walls of

a cavernous tissue with a large network (Fig. 67). The *vaginal mucosa* has a thickness of 1 to 1.5 mm., is normally of a reddish-grey colour, which becomes bright red during menstruation and the excitement of coitus, violet-red during pregnancy, pale in advanced age. It has an *acid* reaction, whilst the uterine mucosa has, as we have seen, an alkaline reaction. It is soft, very distensible and elastic. It consists of a *pavement epithelium* of many strata, which reminds one of the epidermis, and of a *tunica propria* from which rise numerous vascular conical papillae; these are long but they do not project on the free surface, for the epithelium which is interposed fills and levels the inequalities. The tunica propria consists of dense connective tissue very rich in elastic fibres. It contains little lymphatic nodules, is richly furnished with small veins, and is devoid of glands. It adheres closely—without the interposition of a sub-mucosa, to the *external muscular tunic*. This is somewhat less thick than the *tunica mucosa*; it consists of bundles of smooth muscular fibres, disposed in two layers, the internal circular, the external longitudinal. The muscular bundles are interposed with connective tissue very rich in elastic fibres, and supplied with many veins. During pregnancy the muscular and elastic elements become hypertrophied in a distinct manner; after parturition they become reduced; after the menopause they atrophy. The *vulva* or *pudenda* comprise the *external genital organs* (Fig. 68).

These are represented by the *labia majora* which are two large projecting cutaneous folds, which with the thighs brought together are in contact, and cover a median fissure which is the *rima pudendi*. Above the anterior commissure of the labia majora is a cutaneous eminence which is called the *mons veneris*; under the posterior commissure is the *anal aperture*. Opening between the labia majora are two other cutaneous folds called

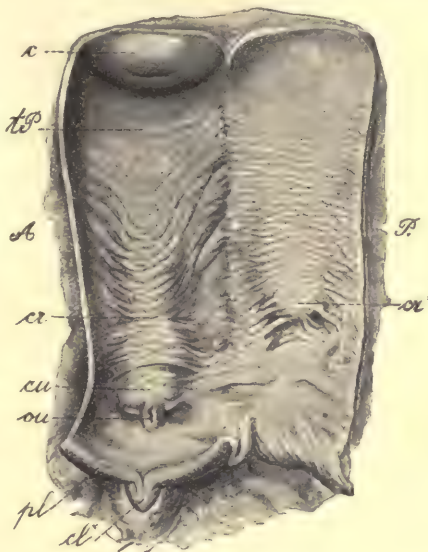


FIG. 67.—Vagina of young woman, opened by an incision along the left margin, including the pudenda: the posterior wall has been detached from the cervix of the uterus and reflected. (Chiarugi.) A, anterior wall; B, posterior wall; C, cervix of uterus; cr, anterior column; cr', posterior column of the rugae; cu, urethral projection; ou, urethral orifice; pl, left labium minor; cl, clitoris; tP, triangle of Pawlik.

the *labia minora* or *nymphae* which enclose between them a shallow cavity called the *vaginal vestibule*, into which open the *vagina* and *urethra*. The *labia minora* join together in front with the *clitoris*, and at the margin of the vaginal orifice with the *bulbs of the vestibule*. More medially situated than the bulbs of the vestibule are two glands called the *vestibular* or *glands of Bartholin*.

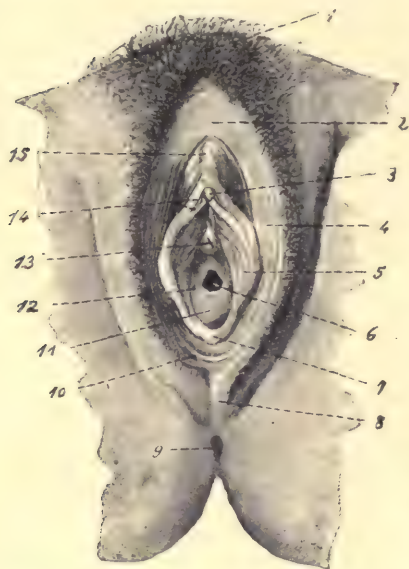


FIG. 68.—Pudenda of virgin; the great and little labia are open and show vestibule of vagina. (Chiari.) 1, mons veneris; 2, anterior commissure of labia majora; 3, glans of clitoris; 4, great labium; 5, little labium; 6, orifice of vagina; 7, frenum of labia minora; 8, posterior commissure of labia majora; 9, anus; 10, perineal margin; 11, hymen; 12, orifice of duct of greater vestibular gland (Bartholin's); 13, external orifice of urethra; 14, anterior extremity of labia minora with medial prolongation which goes to form the frenum of the clitoris and with its lateral prolongation which is continued into the prepuce of the clitoris; 15, prepuce of clitoris.

Without going into a minute description of these parts, which is the task of the anatomist, we will confine ourselves to noting some few particulars which appear most interesting from a physiological point of view.

The labia majora are in the woman the equivalent of the male scrotum. The skin which covers them is pigmented and provided with hairs and sebaceous glands which are among the largest in the whole body, and secrete an oily substance, the odour of which is very aphrodisiac. The skin of the medial surface assumes the appearance of a mucous membrane; it is thinner and is kept constantly moist and lubricated by the sebaceous and sudorific secretions.

Similar to this but more delicate is the epidermoid covering of the *labia minora* or *nymphae*, in which are raised from the underlying connective numerous large papillae which give it a velvet-like appearance. On their lateral surface are numerous little sebaceous glands, which only reach their full development during pregnancy and atrophy at the menopause. The fundamental part of the labia minora consists of connective tissue rich in elastic fibres, bundles of smooth muscular fibres, and large and numerous veins. It presents therefore many of the characteristics of erectile tissue; in fact the nymphae become turgid during sexual excitement. In the interlabial groove there collects, when washing is neglected, a caseous substance having

a strong smell, which is the product of the sebaceous secretion intimately mixed with the desquamated epidermoid elements; it is called *smegma clitoridis* and is analogous to the male *smegma praeputii*.

In the pudenda the erectile organs, which in the male are conjoined in the formation of the penis, are not united in a single organ. The *clitoris*, with its *corpora cavernosa* and its *glans*, represents the corpora cavernosa and glans of the penis; the *bulbs of the vestibule* are morphologically equivalent to the corpus spongiosum of the male urethra.

The corpora cavernosa of the clitoris are similar to those of the penis, but much thinner; in a state of flaccidity they have a length of 2 to 2.5 cm. and during erection a length of 3 to 4 cm. The glans is a conical projection 5 to 6 mm. long which contains cavernous tissue but little developed owing to the preponderating quantity of interstitial connective tissue. The clitoris is covered by a *prepuce* which is a dependent part of the labia minora; its veins are much developed, like those of the penis; its dorsal nerve is distributed specially to the glans, which is rich in terminal corpuscles, even more than that of the penis, and on this account is the most sensitive part of the genital organs.

The *bulbs of the vestibule* (Fig. 69) are two erectile organs shaped like an almond, which converge with their anterior extremities, forming together a kind of horseshoe-shaped organ open behind and surrounding the terminal tract of the urethra and the ostium vaginae. They have been compared to a leech full of blood, which during erection reaches a length of 3 to 5 cm. and a thickness of 1 cm. In structure they resemble the bulb of the male urethra, of which they are the homologue, and, like it, swell during erection but do not acquire rigidity, remaining



FIG. 69.—Bulb of vestibule and clitoris from right side, with veins injected (in blue). (Kobelt-Rieffel.) 1, deep dorsal vessels and nerves of clitoris (artery in red); 2, intermediate venous plexus; 3, glans of clitoris; 4, vestibule of vagina; 5, bulb of vestibule; 6, veins which emanate from posterior extremity of bulb, and discharge into the pudendal vein; 7, veins which join the bulb with the haemorrhoidal plexus; 8, greater vestibular gland (Bartholin's); 9, right root of clitoris; 10, obturator vein.

soft and elastic. The *greater vestibular* or *Bartholin's glands*, are morphologically equivalent to the bulbo-urethral or Cowper's glands of the male which they resemble in form, size, and structure. They possess an excretory duct 1 to 2 cm. long and 2 mm. wide, which opens into the nympho-hymeneal depression at the lateral border of the vaginal orifice. They secrete a viscous fluid like mucus but which does not give the reactions of mucin.

Their secretion is controlled by the perivascular nervous plexuses which proceed from the pudenda and excite a tumultuous ejaculation during coitus or in consequence of masturbation. From the

fact that the points of discharge of these glands are in the *vaginal vestibule*, one may logically conclude that their secretion has no other function than to lubricate the cutis of the penis during coitus, and cannot have any *direct value* in regard to the essential physiological process of conception.

As regards the function of the erectile organs of woman, it is evidently analogous to that of the corresponding organs of man, with this difference, however, that the erection of the penis is a condition indispensable for effecting coitus, whilst the woman may have connection with all its consequences passively, without that exaltation of nervous activity,

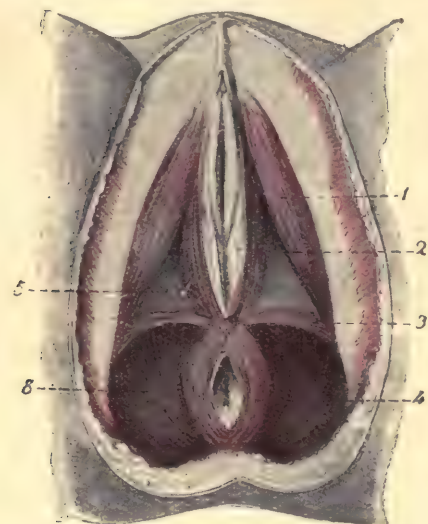


FIG. 70.—Superficial muscles of perineum in female. (Chiarugi.) 1, ischio-cavernosus muscle; 2, bulbo-cavernosus; 3, transversus superficialis perinaei; 4, external sphincter of anus; 5, urogenital trigone, under surface; 6, levator ani.

both general and local, which determines erection and ejaculation. The mechanism of erection of the external genital organs of woman is exactly the same as that which we have described in man. The erection of the clitoris and of the vestibular bulbs in woman is also a reflex action determined by sexual excitement of the higher senses, and specially by the mechanical stimulation of the sensitive, vulvar and vaginal surface produced by the introduction of the penis. The reflex promotes the active dilatation of the afferent arteries of the erectile organs and the consequent afflux of blood which causes them to become turgid. The *ischio-cavernosus* and *bulbo-cavernosus* muscles have in woman the same function as in man (Fig. 70), that is, they

increase the erection of the clitoris, as well as that of the bulbs, by compressing the effluent veins of these organs. They may also favour ejaculation by pressure on the vestibular glands of Bartholin. A peculiarity worthy of note is that the clitoris in becoming turgid and rigid does not rise upwards like the penis, but lengthens below towards the vaginal orifice (as Fig. 69 shows), placing itself in contact with the dorsal surface of the penis during coitus and receiving the repeated friction which for the woman is the principal source of voluptuousness.

With the prolongation of coitus, and the voluptuous sensation, the reflex movements extend to all the muscular parts of the female genital apparatus: the *bulbo-cavernosus* muscles contracting rhythmically constrict the vulvar cleft (whence the name of *constrictor cunni*) compressing rhythmically the root of the penis and prolonging its erection, whilst the spastic contraction of the muscular layers of the vagina compress it around in all its length. In those women who are most sensitive, the acute paroxysm of voluptuousness which determines these reflexes arises after spermatic ejaculation has happened in the man, and causes a prolongation of the copulation, rendering extraction of the penis from the vagina occasionally difficult and even painful.

In some animals, for example in dogs, this phenomenon is always much accentuated, and causes prolongation of the copulation for some minutes after the embrace *a posteriori* has ceased, and when the two conjoined individuals are separated violently, there is great pain occasioned, specially to the male. This is due to the extraordinary development of the glans, in comparison with the corpora cavernosa of the penis of the dog, with the result that, being wedged in the vagina, it cannot be withdrawn until the spasm of the constrictor vulvae has ceased.

V. The fertilisation of the ovum is dependent on its *impregnation* with the sperm, or more strictly the *meeting* of the male element or *spermatozoon* with the *ovum* or female element. It is necessary, therefore, to make clear the mechanism by which the sperm ejaculated from the penis in the vagina is able to reach the ovum, which has escaped in consequence of the bursting of an ovarian follicle.

By what process do the spermatozoa penetrate into the uterus and the oviduct to reach the ovum? The sperm cannot be injected directly into the womb through the cervical canal, because normally the axis of this canal forms almost a right angle with the vaginal axis, in the direction from which ejaculation takes place (Fig. 59). On the other hand, the sperm cannot remain for any length of time in the vagina, because the spermatozoa, owing to the acid surroundings, suspend their movements, and after a short time lose the capacity altogether. If we consider the *orifice of the uterus*, through which the sperm must

penetrate, it presents notable differences according to the age and the previous activity of the organ, and in healthy women there is often to be seen projecting from it a plug of mucus secreted by the cervical canal, clear, viscous, and *alkaline* in reaction (Fig. 71).

Even in apathetic women who do not take any active part in coitus, as also in women who are unconscious, or have fainted during forced criminal connection, it is an undoubted fact that the sperm ejaculated into the vagina can enter through the cervical canal; on this account it must be admitted that this penetration can happen independently of any activity of the uterus or vagina. This being the case, what is the mechanism of penetration? The experiments of Seligmann (1896) make it very probable that this happens by a *negative chemotaxis* of the spermatozoa to the acidity of the vaginal mucosa, and by a *positive chemotaxis* to the alkaline *mucous plug* which normally projects from the external orifice of the uterus; in this way they pass quickly from

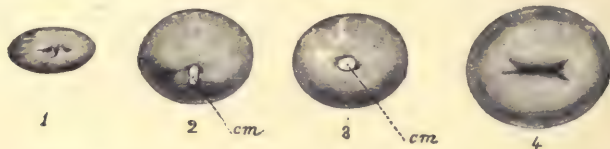


FIG. 71.—External orifice of uterus. (Waldeyer.) 1, of child; 2, 3, of nullipara; 4, of multipara; *cm*, mucous plug.

acid surroundings into alkaline, in which they can travel through the cervical canal, and penetrate into the body of the uterus.

But in women who take a more or less active part in sexual intercourse, and they are—I believe—the great majority, it must be held that all the genital apparatus provided with contractile elements, by participating in the sexual act, favours in various ways the penetration of the sperm into the uterus. From their observations, many gynaecologists conclude that during coitus the vagina, with its rich muscular supply, as well as the uterus, with its muscular walls and muscular round ligaments, contract, and enter into a condition of more or less intense excitation. In this connection the mode of action of the mouth of the uterus is of interest; this the English gynaecologist, J. Beck, observed directly in a woman affected by prolapse of the uterus and in whom the os uteri showed itself through the vulva. It was sufficient to excite the projecting neck with the tip of the finger to produce within a short time the venereal orgasm. "The uterine neck (wrote Beck) at the beginning was hard, immobile, and had the normal aspect: its aperture was closed and did not admit the passage of a sound. Almost immediately after contact with the finger the mouth opened widely, gaped 5 or 6 times,

and was drawn vigorously into the interior of the cavity of the neck. These phenomena lasted about 20 seconds, then everything returned to the normal state, the opening closed again, and the neck reassumed its position. . . . When I add that the patient was very intelligent, that there was no inflammatory state, either in the mouth or neck of the uterus, or in the vagina, and that only a displacement existed, one will be able to believe with me that this is evidence of what occurs during coitus, and that the passage of the spermatie fluid into the uterus may thus be clearly explained."

It is therefore undeniable that the sperm, discharged normally in the immediate vicinity of the uterine neck, may, through the descent of the uterus, caused by its erection and the simultaneous contraction of the vagina, be aspirated into the cervical canal during the rhythmic movements of the "trench mouth," which Beck picturesquely calls gaping; even in this case, the efficacy of chemotactic phenomena already described is not excluded. It is more difficult to explain how the sperm which has penetrated into the uterus ascends to the oviducts, for the cilia of the uterine epithelium have constantly a movement directed from above downwards. It is possible that the ciliary wave acts on the spermatozoa, exciting them to move "against stream." This kind of *rheotactic reaction* of the spermatozoa is most probably a *chemotactic reaction* on their part to the ovum, because—as Verworn observes (1894)—the spermatozoa move against the current even when maturation of the follicle and the passage of the ovum through the oviduct have not occurred. Roth (1893) also observed the phenomenon of *positive rheotaxis* in bacteria as well as in spermatozoa.

The locomotion of the spermatozoa, due—as we have seen in the preceding chapter—to the special oscillations of the tail, is sufficiently rapid to enable them, under the most favourable conditions, to pass through a distance of 1 to 3 mm. in a minute; so that to pass over in a straight line the tract of 16 to 20 cm. which stretches from the external opening of the uterine neck to the infundibulum of the Fallopian tubes, would require about three-quarters of an hour. Experiments and observations on animals, however, show that several hours may elapse between coitus and the arrival of the spermatozoa at the tubular infundibulum.

The ovum differs from the spermatozoon in not being capable of moving itself by its own efforts, and is impelled passively by extrinsic forces around it. Considering the anatomical relations between the ovary and the ovarian infundibulum, and the ease with which they change their position according to the position of the body, it is difficult to explain by what process the ovum, after the bursting of the Graafian follicle, is impelled towards the infundibulum, and through the oviduct. It is supposed by

many, without, however, any proof, that the ovary is usually embraced by the infundibulum with its numerous fimbriae; that this immediate contact of the surface of the ovary with the tube is facilitated by the state of turgidity of both organs during and after coitus. There has also been suggested the intervention of the muscular fibres of the extremity of the tube, by which might be carried out active movements directed to secure the ingress of the ovum into the oviduct. These suppositions are all gratuitous, or directly contradicted by observations on animals. It has been demonstrated, however, by Kossman (1903) that the very numerous fimbriae of the infundibulum, with the ciliated epithelium with which their internal surface is provided, act in their entirety as a powerful aspirator, capable of producing a continuous current, directed towards the tubal canal, which sucks up and transports towards the uterus all the corpuscles which happen to be in the liquid expelled from the burst follicle. The ovum, therefore, can be easily aspirated and drawn into the oviduct, whatever the position of the burst follicle on the surface of the ovary or its distance from the tubal canal.

Arrived in the tube, the ovum proceeds towards the uterus very slowly, either by the direct impulsive action of the cilia of the epithelium which lines the canal, or through the effect of the peristaltic contractions of the muscular wall, contractions analogous to those which take place in the vas deferens of the male during ejaculation of the sperm (Kossmann). The latter mechanism appears more probable, for the oviduct, especially in the isthmus, is somewhat narrow, which accounts for the fact that the ovum may stay several days in the oviduct, and may occasionally become adherent and develop there, if it has been fertilised (*tubal pregnancy*).

Where does the meeting of the spermatozoa with the ovum, which makes possible the fundamental phenomenon of fecundation, occur? In order that fertilisation may take place, it is necessary that the ovum should divest itself of the cells of the *cumulus oophorus* which surround it when it is expelled from the follicle, and should present its *zona pellucida* bare, before a covering is formed round it, as happens during its passage through the oviduct. It is therefore very probable that the meeting of the two sexual elements occurs in the abdominal cavity, and precisely in the tract which lies between the burst follicle and the infundibulum of the tube (Strassmann). That the sperm can reach the ovary is shown by the old observations of Bischoff (1844), who saw in mammals that, within a short time of copulation, the surface of the ovary was covered with spermatozoa. The cases of *ovarian and abdominal pregnancy* would be inexplicable without admitting that the meeting of sexual elements and the consequent fertilisation may take place in the abdominal cavity. To-day

physiologists and gynaecologists agree in accepting this theory as a general rule, and consider also that the changes in the fertilised ovum, that is pregnancy, commence always in the tube. When the unfertilised ovum arrives in the uterus, it is no longer capable of fertilisation, and is destined to be expelled after a longer or shorter time (in dogs after eight to fourteen days).

With this question is connected another interesting problem. Are the sexual excitement of coitus, and the congestive state which accompanies it, capable of causing the rupture of a Graafian follicle in course of maturation, as occurs periodically at menstruation? The fact that woman can be fecundated at any time, even in the interval of about ten days during which the uterine mucosa is in the resting stage, in distinction to the mammals, in which coitus and fecundation occur only during the period of "heat," speaks in favour of this old theory; it agrees, moreover, with the popular belief that sexual intercourse proves more fruitful the greater the co-operation and sexual ardour the woman displays during the connection. Slaviansky, Leopold, and Romiti maintain anew this old view, which is not contradicted by any fact, but at the same time is not supported—so far as I know—by any direct experimental proof.

In fact, to account for fruitful coitus, not coincident with the time which immediately precedes or immediately follows the menstrual period, it is not difficult to suppose that the sperm, having arrived at the ovary, retains its vitality there for several days, until maturation and the bursting of the follicle which precedes menstruation takes place; or that the ovum expelled in the menstruation previous to coitus remains for some days in the peritoneal cavity, before being impelled along the oviduct into the uterus, so that it may be reached later by the sperm and impregnated.

Of these two views, that the spermatozoa wait for several days the rupture of the follicle in order to fecundate the ovum, or on the other hand that the ovum expelled from the follicle remains several days in the abdomen before being impregnated, the first is certainly more worthy of attention, for it has been observed that the ovum expelled from the follicle loses after a short time the capacity of being fertilised, whilst the spermatozoa which have arrived at the ovary preserve for a long time their vitality and capacity of movement and fertilisation (*v.* page 127). But let us declare frankly, although the contrary opinion now obtains, that the simplest hypothesis, which gives a true *teleological value* to the venereal orgasm which accompanies sexual intercourse in the woman, is that maintained by Slaviansky, Leopold, and Romiti.

VI. We pass now to consider the culminating physiological act which makes possible the whole process of reproduction of the

species : *Conception*, that is to say, *fertilisation* of the female sexual cell (*ovum*) by means of the male sexual cell (*spermatozoon*). The history of the scientific discoveries in regard to this important part of physiology begins with the demonstration that fertilisation cannot take place except by means of a *direct action* of the sperm on the ovum. Priority in this demonstration belongs to Spallanzani (1786), who, in his celebrated experiments "*On Generation*," succeeded in fertilising the ovum detached from the body of the frog by placing it in *immediate contact* with the sperm expressed from the testicles, the vesiculæ seminales, and the deferent ducts of the male. The *artificial fertilisations* of Spallanzani were then repeated with success by Rusconi on the ova of fishes. Spallanzani and Rassi succeeded first in fertilising a bitch by injecting with a syringe the sperm of a dog. Spallanzani discovered that after diluting 3 grms. of sperm with 18 c.c. of water, one drop of this liquid was sufficient to fertilise many ova of the frog.

An English experimenter, Haighton (1797), tied one of the oviducts of a bitch, and observed that fertilisation did not take place in the corresponding uterine cornu, while it occurred regularly in the opposite one.

These facts served to overthrow many old theories on fecundation, for example the view that the influence of the whole organism of the male on the female was necessary; and the other, maintained by Graaf and widely spread among the old physiologists, that the fertilising action of the sperm could be transmitted to a distance by the so-called *aura seminalis*.

Definite proof that in the mammals also fecundation is brought about by the immediate contact of the ovum with the spermatozoon was supplied by the experiments of Prevost and Dumas (1824). They demonstrated that filtered sperm is not capable of fertilising because it is deprived of spermatozoa. Bischoff (1844), having killed a bitch a few hours after coitus, recognised the spermatic animalculæ in the vagina, the uterus, the tubes, and its fimbriae, the peritoneal cavity, and on the external surface of the ovaries. The fact that for fecundation *external contact* of the spermatozoon with the ovum is not sufficient, but that *mechanical penetration* into the middle of it is necessary, either through the so-called *micropile* or through the supposed *pores* or canaliculi of the zona pellucida, was demonstrated for the first time by Barry (1843) in the rabbit. Ten years later his observations were confirmed by Meissner, and by Bischoff, and extended afterwards by many other investigators upon lower animals.

The morphological process of fertilisation has been the subject in recent times of numerous and ingenious experiments to clear up if possible the most obscure mysteries of reproduction. The inquiries were extended to the infusoria, to the embryonic sac of

the phanerogams, and the ova of animals, with results which were sufficiently in agreement. We shall limit ourselves to pointing out briefly the principal phenomena observed in ova. Before being expelled from the follicle, or immediately after, the ovum undergoes a preparatory process called *maturation* which renders it capable of being fertilised. It consists of an *unequal karyokinetic division* of the ovum cell (*gemination* or *germination*), which leads to the formation of *directive corpuscles* or *polar bodies*, so called because it is supposed that they indicate the point of the pole of the ovum from which starts the cellular segmentation that takes place after fertilisation. While the germinal vesicle dissolves,

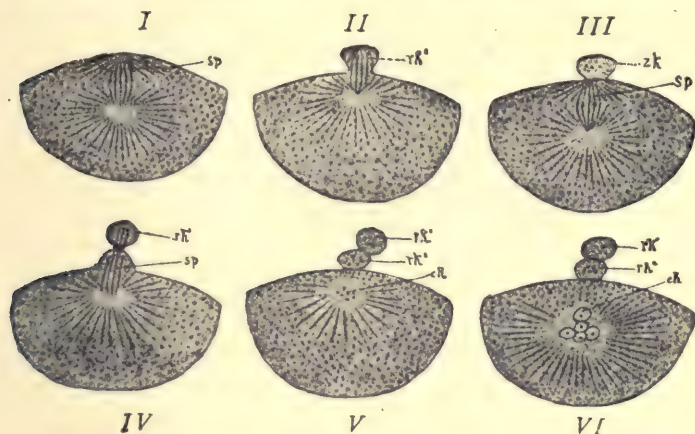


FIG. 72.—Formation of polar bodies in ovum of *Asterias glacialis*. (After O. Hertwig.) I, the nuclear spindle (*sp*) has reached the surface of the ovum; II, at the surface of the ovum a little nipple has formed (*rk'*) which contains half the spindle; III, the nipple has separated by constriction and constitutes a polar body (*zk'*), while from the interior half of the original nuclear spindle there is developed a complete new spindle (*sp*); IV, the first polar body is raised by the formation of a second nipple (*sp*); V, the second nipple has separated from the ovum to constitute the second polar body (*rk'*); VI, the remainder of the second spindle has transformed itself into the nucleus of the ovum (*ck*).

there is formed at the expense of its contents a *nuclear spindle* with two *polar radiations* at its extremities. This spindle approaches gradually to the pole of the ovum, until it touches the surface of it with its extremities (Fig. 72). At this point of contact, the yolk of the ovum rises, and protrudes in the form of a nipple, which afterwards contracts at its base, and finally separates with part of the yolk and half of the spindle, and constitutes a little polar body. The same process repeats itself, after the half of the spindle remaining in the ovum has transformed itself again into a complete spindle; thus is formed a second little polar body, and the process of maturation of the ovum is complete.

The semi-spindle remaining in the ovum cell after the emission of the two polar bodies is called the *ovarian* or *female pronucleus*.

It leaves the periphery of the yolk to approach the centre, where it waits to be fertilised.

The process of fecundation, as that of maturation through which are formed the polar bodies, has been well studied in the transparent ova of the echinoderms and ascarides. When the two sexual elements are mixed in sea water, a great number of spermatozoa soon approach the ovum, and fix themselves on the gelatinous envelope.

But *one only of them normally penetrates the ovum and fertilises it*. At the point where it touches the ovum with the extremity of the head, the hyaline protoplasm forming the cortical stratum of the ovum rises into a little prominence called the *cone of attraction* (Fig. 73), which the head of the spermatozoon penetrates with its active pendular and boring movements. The spermatozoon having

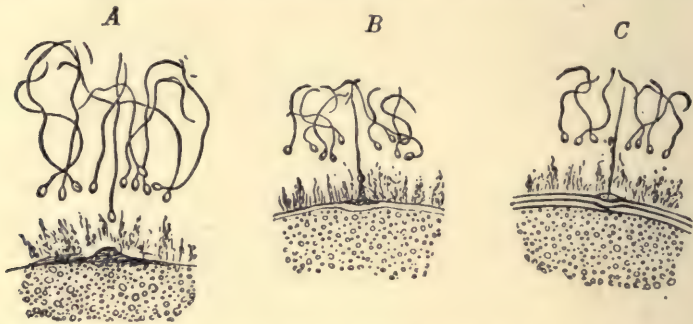


FIG. 73.—Portions of ovum of *Asterius glacialis* during the *copula externa* with the spermatozoon. (According to Fol.) *A*, the spermatozoa have already come in touch with the mucous covering which invests the surface of the ovum, which begins to push out a prominence in front of the spermatozoon which is nearest to it; *B*, the prominence and the head of the spermatozoon have made contact; *C*, the head of the spermatozoon has penetrated into the ovum and at the place of penetration the ovum has formed a vitelline membrane.

penetrated into the ovum, the aperture is closed by the secretion of a fine *vitelline membrane*, which prevents the entrance of a second spermatozoon.

To the *copula externa* of the two sexual cells succeeds the *copula interna*, that is the act of *fertilisation properly so called*. The head of the spermatozoon having penetrated into the ovum, grows rapidly in volume and acquires the appearance of a vesicle, which is called the *male pronucleus*, whilst the tail ceases to move and dissolving gradually soon disappears. The male pronucleus leaves the peripheral zone of the ovum and approaches the centre in the direction of the female pronucleus. During this centripetal movement a special attraction appears to be exercised on the granules of the yolk, for they dispose themselves around in the form of rays, which become always more distinct and extended. While the male pronucleus is approaching

the female pronucleus, this also moves somewhat to meet it, until the two come into contact in the centre of the ovum and after 20 minutes form a new *complete nucleus*, which is immediately surrounded by an aureola of homogeneous protoplasm from which emanate the rays of a common star (Fig. 74). With the fusion of the two pronuclei is fulfilled the *great act of fertilisation*, that is the formation of the *nucleus of segmentation*, with which is initiated the whole embryogenic process of a new being; in other words, the nucleus of segmentation represents the *germ* of the individual to be born, because it contains all the determinants of the characteristics, both somatic and psychic, which will go on producing themselves and developing during ontogenetic evolution. The glory of the discovery of these phenomena of the *maturation*

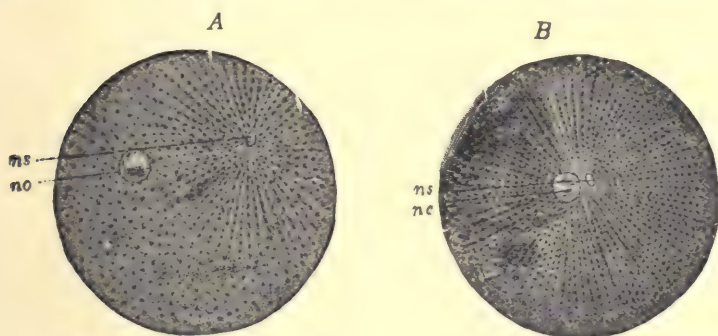


FIG. 74.—Fertilised ovum of echinoderm during the *copula interna* of the male pronucleus with the female pronucleus. (According to O. Hertwig.) A, the head of the spermatozoon having penetrated into the ovum is transformed into a spermatic nucleus (ns) or male pronucleus, about which are formed protoplasmic rays; the nucleus or female pronucleus (no) is some distance from ns; B, no and ns approach, to fuse together in the complete nucleus of segmentation and are surrounded by star-like protoplasmic rays.

and *fertilisation* of the ovum is divided amongst an elect band of observers, of whom I will limit myself to indicating the most meritorious: van Beneden (1883-87), Boveri (1887-90), O. and R. Hertwig (1875-90), Bütschli (1876-84), and Fol (1883-91). Although these phenomena have been observed with greater detail in the ova of the echinoderms and ascarides, there are not wanting, however, observations on different classes of animals, including the mammals, for example on the rabbit by van Beneden.

There is no doubt then that they have a general value; they are confirmed, more or less modified in the more minute and accessory particulars, throughout the animal kingdom. They form the starting-point of many interesting considerations of a philosophical character, to a few of which we shall with much reserve make some reference.

What are the differential characters of the two sexual elements? What value or physiological significance must we

attach to them? The *male cell* or *spermatozoon* is perhaps the smallest, the most mobile cell of the organism, and amongst the most resistant to external agencies; the ovum or female cell is perhaps the largest, one of the least mobile, and is amongst the most delicate and vulnerable. When it is expelled from the Graafian follicle, the human ovum is a globule with a diameter of 200μ ; the human spermatozoon is a very fine filament which—including the head—measures 50μ in length. Evidently these differences in size, form, mobility, and resistance are co-ordinated with their different functions as sexual cells: the spermatozoon is the more active element, destined to move in search of the ovum, to fertilise it; the ovum is the less active element, destined to receive the spermatozoon, to be fertilised by it, and to furnish to the *germ of the new being* its first aliment. Nature, according to the principle of division of labour, has allotted to the two elements opposite sexual properties which would be irreconcilable in one single element; accumulating on the one hand, in the ovum, the substances necessary for the nutrition and multiplication of the cellular protoplasm necessary to keep pace with the rapid development of the germ of the new being; on the other hand, reducing the spermatozoon to a contractile filament, divesting it of the vitelline and protoplasmic substances which would impede its motor activity, and giving to it a form capable of passing through the protective covering with which the ovum is invested and penetrating to the yoke.

This differentiation of the two sexual cells becomes more and more accentuated in the gradations of ascent of living beings, probably by successive and continuous adaptation, or by hereditary selection and transmission. It is to be noted, however, that it is concerned chiefly with the secondary characters of the two elements, and has no intimate relationship with the essential phenomena of fertilisation, that is, with the *copula interna* of the *two sexual elements*. This is in fact accomplished specially by the union of the two nuclear portions of the male and female cells; each of these pronuclei contributes to the formation of the *complete nucleus of segmentation*, which we have called “the germ of the being to be born.” Whatever the difference in size, form, and properties between the ovum and spermatozoon, they contribute to fertilisation nearly equal amounts of their active nuclear substance, in which our means of investigation do not enable us to discover the least difference. “There does not exist then (wrote O. Hertwig) a fecundating substance specifically feminine, or a fecundating substance specifically masculine. The two nuclear substances which unite in fecundation do not differ one from the other, except in proceeding from two different individuals. Fecundation is not the neutralisation of two *sexual antitheses*, because these antitheses are only based on characters of a secondary order.”

These assertions contradict the hypothesis of *hermaphroditism of the nuclei* maintained by Minot (1882) and specially by van Beneden (1884). This hypothesis is founded on the phenomena of maturation of the ovum, by which the polar bodies separate, and the equivalent phenomena of the detachment of the spermatozoa from the spermatoblasts. The nuclei of the ova and of the spermatozoa before their maturation would be hermaphrodite; the former do not acquire their female sexual characters until after they have rid themselves of the male parts of their hermaphrodite nuclear apparatus by the elimination of the polar bodies; the latter do not acquire their male character until they have abandoned in the spermatoblast the female part of their hermaphrodite nucleus. After maturation, the pronucleus of the ovum, and the pronucleus of the spermatozoa acquire opposite sexual characters, and fecundation consists in the substitution of the male elements expelled from the ovum by those conveyed to the ovum by the spermatozoon. This ingenious theory of the *hermaphroditism* of the immature sexual elements, and the *substitution* of the male sexual part of the ovum by that of the spermatozoon in the act of fecundation, does not bear critical examination alongside better ascertained facts relative to the process of reproduction in the whole world of living beings, which demonstrate *original asexuality*, that is the equivalence of the male and female pronuclei, from the fusion of which results the germ of the new being. According to this view, the maturation of the ovum, meaning thereby the expulsion of the polar bodies, does not signify the transformation of a hermaphrodite element into a female element, but simply the diminution by half of the nuclear substance, the chromatin of the ovum, so as to render possible the substitution of another equivalent substance, different only in proceeding from another individual sexually differentiated. Without going through the vast field of the comparative physiology of fecundation, we will limit ourselves to summing up in a few general propositions the results of numerous observations, confining ourselves specially to the studies of O. Hertwig.

(a) In order that fertilisation may occur, it is necessary that the sexual elements be *fertile*, that is, possess certain definite tendencies, and be sexually akin, in other words, reciprocally adapted one to the other and with a tendency to unite. We are as yet ignorant of the real nature of *fertility* and *sexual affinity*.

(b) *Fertility* presents itself periodically in the life of the cell; it is of short duration; it depends to a certain extent on external influences, and in many cases may be abolished and transformed into *parthenogenesis*, i.e. *virgin generation*, or into *apogamia*, i.e. *alternation of generation*.

(c) Sexual affinity is expressed by the reciprocal action which the fertile elements exercise at a certain distance, so that they

approach, unite, and fuse together. The success of the fertilisation depends on the degree of affinity existing between the two sexual cells, *not upon difference but upon similarity of their intimate organisation*. When the relationship is too near or too remote, that is, when the resemblance or the dissimilarity is too slight, or too great, the success of the fertilisation is compromised in an absolute or a relative manner. "The crossing of forms," wrote Darwin, "which have been exposed to conditions of life a little different, or which have undergone variations, favours the vital energy and fertility of their descendants, while more considerable variations are often unfavourable."

To illustrate these general propositions with a particular example I think it will be useful to refer to the most recent experiments carried out at the zoological station of Naples by von Dungern (1901) on echinoderms. When the ova and spermatozoa of the star-fish (*asterias*) and the sea-urchin (*echinus*) are placed in a vessel of sea water, it is seen that the spermatozoa of one species are attracted by the ova of the other species promiscuously, without, however, fertilisation and the generation of bastard products taking place. According to the observations of von Dewitz, confirmed by von Dungern, the presence of the ova of one species exercises on the spermatozoa of another species a stimulating influence, which makes them more lively, but at the same time changes the direction of their movements, so that they slide with their heads oblique on the surface of the ovum in a manner that does not enable them to penetrate and pass into the yolk. On the spermatozoa of the same species, however, the ova exercise a certain inhibitory and directing action, so as to enable them to place their heads in the proper position that they may penetrate into the yolk and fertilise them. This then is a complex process determined by forces difficult to reduce to a simple *chematactic action*.

According to the new researches of von Dungern, fertile pairing between the sexual elements of different species may be also hindered by two other mechanisms. From the ova of the star-fish he isolated a substance resistant to heat, which proves poisonous in very small doses to the spermatozoa of the sea-urchin, but not to those of the star-fish: in the ova of the sea-urchin, on the other hand, such a substance, poisonous to the spermatozoa of the star-fish, was absent; the spermatozoa may make contact with the ova of the echinus without dying, but cannot penetrate and fertilise them, because they become agglutinated in the gelatinous coverings which wrap them round.

These results appear the more interesting when one recalls the modern researches on immunity inaugurated by Ehrlich, from which the conclusion is drawn that the animal organism is endowed with the capacity of forming, under certain circumstances,

special substances which serve to protect it against pathogenic microbes, and against the toxins which they produce, agglutinating the first and neutralising the second by means of antitoxins.

VII. We have said that the ovum and the spermatozoon by the union of their two pronuclei form the germ of development of a new organism. Now it is noted that the organism so generated reproduces the characters, both physical and psychical, of the parents, not only the more generic characters, but also those more peculiar to the species, and even to the individuals who have co-operated in reproduction. This common and every-day observation compels us to admit that the germ which results from the union of the sexual cells, contains in itself all the conditions and characteristics necessary for the building up of the final product of its development. These conditions and characters are *latent* in the germ, that is, in a state of simple *tendencies*, and reveal themselves to our senses progressively during development. Since it is impossible to imagine these *tendencies* without admitting that they have in the fecundated ovum a *somatic substratum*, it follows that the organism evolved must be in some manner *performed*, that is, contained potentially in the complex of the tendencies and their substrata. Nägeli wrote in reference to this: "The fertilised ova contain all the essential characters of the completely evolved organism; they do not differ less, one from another, than do the adult organisms themselves. In the egg of the fowl, the species is contained as completely as in the fowl itself, and the egg of the fowl is not less different from the ovum of the frog than the fowl differs from the frog."

In order to account in some way for the undeniable relation between the *germ* and the *evolved organism*, between the *invisible* characters and those which become *manifest* during development, there were propounded in the past two principal theories, on the criticism of which is based the modern *doctrines of generation and heredity*, certainly the most difficult, loftiest, and most important problems of physiology. The most celebrated and gifted naturalists and physiologists of the seventeenth and eighteenth centuries, Swammerdam, Malpighi, Leuwenhock, Haller, Bonnet, and Spallanzani, maintained the *theory of evolution* which to-day one is accustomed to call by the clearer and more appropriate name *theory of preformation*. They held that the germs were from the beginning identical in their structure with the adult organism, that is, they contained in minute dimensions and hence invisible all the organs of the adult, and in the same special relations in which they are found in adults. As from the bud unfolds the flower, as from the chrysalis is developed the butterfly, so from the fecundated human ovum develops the adult man; the ovum is the *homunculus*, it is man in miniature, which contains all the characters somatic and psychic which expand and display them-

selves during the development through which the *homunculus* becomes the *homo sapiens*. The most vulnerable point of this theory is that in the superior organisms each individual is developed by the co-operation of two generators of opposite sex.

When in 1677 Leuwenhock described the spermatozoa, an ardent discussion arose on the question whether the preformed germ was represented by the ovum or the spermatozoon. The dispute between the *ovists* and the *spermatôzoists* lasted a century. The former, amongst whom Spallanzani ranged himself, considered that the ovum was the organism in miniature, and that the spermatozoon had no other office than to excite it, and promote its growth; the latter, on the other hand, looking at the spermatozoon with the microscope, claimed to distinguish in it besides the head, also the arms, the bones, in fact the principal organs of the adult, reduced to the lowest terms. For them the spermatozoon was the organism in miniature, and the ovum was only the nutritive medium necessary for its growth.

Gaspar Frederick Wolff, in his thesis for the doctorate maintained in 1759 and published in 1764, performed the service of substituting for the dogma of preformation the scientific principle that there cannot be admitted as existent in the germ that which the senses are incapable of perceiving. For him the germ is primarily only a secretion of the genital organs of the generators, without organisation in fact. It is in consequence of fertilisation that it is organised gradually during development.

According to this theory, which was called that of *epigenesis*, the organs were differentiated one from the other at the expense of the *originally undifferentiated germinal substance*. Guided by observation Wolff traced the first stages of this process of differentiation, and laid the foundation of the magnificent edifice of the embryology of the last century.

The theory of epigenesis, however, as it was conceived by Wolff, and developed and perfected by embryologists after him, met with great opposition.

How was one to admit in fact that the natural forces known to us should succeed in transforming in a few days, or weeks, unorganised matter into an animal organism similar to the generators? An entirely new organisation from a substance quite unorganised resembles too much a *creatio ex nihilo* to be admitted, for it is incapable of any scientific explanation whatever.

The *nisus formativus* imagined by Blumenbach, which impels the unorganised paternal and maternal reproductive juices to assume a determined form during development, to repair losses or waste of organs, and sometimes even casual mutilations which may occur to the adult organism, is nothing more than a vague expression, which does not at all explain the unknown phenomenon,

but serves only to emphasise the fact that it is inexplicable by natural laws.

The modern views about generation, the constitution of the germ as a sketch of the adult organism, its rapid development, and the inheritance of the parental characteristics in the offspring, are based upon the *cellular theory* formulated by Virchow towards the middle of last century, and perfected by degrees up to the present time. On the basis of the *cellular theory*, it is admitted at the present time: (a) that the ova and spermatozoa are cells detached from the organism for the purpose of reproduction, and that adult organisms themselves are only associations, well arranged and connected, of numerous cells transformed, and adapted according to the principle of division of labour for different functions, but all proceeding from the division, millions of times repeated, of the cells derived from the fertilised ovum.

(b) That the cell is not a substance without organisation, but a very complex structure which constitutes by itself an *elementary organism*, capable of living in its natural surroundings, independently or associated with others.

(c) That the cell represented by the fertilised ovum is the most complex cellular structure of the higher animals, that is, the element which has an internal organisation perfectly comparable to that of the organism which is developed from it.

(d) That the foundations of the theory of generation and heredity must be sought in the knowledge already gained, and to which we have referred in connection with the process of fecundation, the structure and division of the nucleus of the ovum, the maturation of the two sexual elements, the fusion of the male with the female pronucleus, the equivalence of the male and female pronuclei in the fecundation of the mother cell, and their division in the daughter cells.

The modern theories of generation and heredity are bound up with the names of C. Darwin (1879), Spencer (1876), Nägeli (1884), O. Hertwig (1884), Strassburger (1884-88), Weismann (1883), and de Vries (1889). In their views the sharp antithesis between the two old theories of *preformation* and *epigenesis* is in great part reconciled; they are in fact intermediate between the two, and represent a perfecting of each. For a minute knowledge of these theories I refer the reader to the original works. I will limit myself here to observe that whatever may be the differences between them on accessory particulars, they agree in essential points, on which alone we shall dwell briefly.

To account for reproduction and heredity, we are forced to admit the hypothesis that the development of the germ does not consist in a new formation or epigenesis, but rather in the *transformation of a model or rough sketch into a complete organism*, capable in its turn of forming a model similar to that from which

it was itself derived. Nägeli gave the name of *idioplasm* to the hereditary substance represented by the sexual pronuclei which fuse together in the act of fertilisation; the germ which results from it contains the images of the two individuals from which it arises, and is therefore capable of transmitting by heredity their characters to the individual which develops from it. It is, moreover, necessary to admit that the *idioplasm* is a kind of *microcosm* from which will develop the *macrocosm*, resulting from a myriad of particles, materially different, and disposed in a certain regular order, bearers of hereditary characteristics and tendencies, and endowed with peculiar and special energies. To these particles different names were given by different authors; as representing the elementary components of *idioplasm*, we shall follow O. Hertwig in calling them *idioblasts*. "As physics and chemistry (wrote de Vries) go back to molecules and atoms, so the biological sciences have for their objective these units (*idioblasts*) in order to explain from their combination, the phenomena of the world of living beings."

Nägeli also thought that the anatomical structures and the physiological functions, which we perceive in the adult organisms in the most complex conditions, are reduced in the *idioplasm* to their most simple elements (represented by the *idioblasts*).

With the insufficient scientific knowledge which we possess to-day, we are not in a position to state or even to imagine in what consists the specific nature of the different *idioblasts*; however from the definition alone of *biological units carrying hereditary characters*, we may draw some conclusions relative to their more general properties.

As we attribute to the cells, which are the elements of the complex organisms, all the vital specific properties by which living beings are distinguished from inorganic bodies; so it is necessary to attribute to the *idioblasts*, which are the essential elements of the cells, all the vital properties by which the cells are differentiated from organic substances without organisation. It is easily understood that the *idioblasts* must *grow and multiply by division* as do the cells. In fact, all the daughter cells proceeding from the mother cell, represented by the fertilised ovum, must contain special *idioblasts* arising from the ovum, without which the adult organism could not repeat the characters of the parents, nor be capable of forming in its turn the sexual cells which in their *idioplasm* contain the sum of the hereditary elements represented by the *idioblasts*. It is then a strictly logical consequence that the *idioblasts* of the ovum grow and multiply by division during the development of the germ. Through their divisibility the *idioblasts* are clearly distinguished from the *molecules* of physics and chemistry, which cannot divide without changing their nature and characters. We must then imagine them as very complex

aggregates, represented at least by groups of molecules, endowed with a very complicated constitution and organisation, in other words we cannot picture them merely as little masses of idioplasm. Finally admitting that the whole adult organism, in so far as it reproduces the hereditary characters of the parents, is only the result of the multiplication and partition among the different organs, tissues, and cellular elements of the idioblasts contained in the germ, we must logically allow in the germ, as it is the model of the organisation to be born, a *regular ordering* of the myriads of idioblasts which compose it!

Although, therefore, the old *theory of preformation* may be false in the absolute form, which saw in the germ the adult organism in miniature, there is in it a grain of truth, for one must admit in the elements which compose the hereditary substance, a very fine organisation and ordering of relations not less complex than that which is observed in the evolved organism. On the other hand, the *theory of epigenesis* was false so far as it saw in the development of the germ, a complex neoformation from a substance originally neutral, but it was true in that it admitted, during development, the successive multiplication of the elements from which the tissues, the organs, and the systems arise.

VIII. To complete what we have said in the present chapter about the functions of the female genital apparatus, it only remains to treat of the ovary as an organ which exercises a notable influence, not only on the other parts of the apparatus itself, of which we have spoken on page 176, but also on the whole organism—as we did in the preceding chapter in regard to the internal secretion of the testicle (*v.* page 152). To form some idea of the importance of the functional activity of the ovary in respect to the regularity of the course of all the great functions of the whole organism, it is sufficient to take account of all the abnormal phenomena which are to be observed in woman at the time of the menopause, when the ovary by a process of involution ceases to function as an organ of ovulation, menstruation is abolished, the uterus and the other parts of the genital apparatus, as well as the mammary glands, atrophy. Coincident with these local changes arise noticeable disturbances in the whole of the economy, specially in reference to the central nervous system—disturbances so common, that they may find a place in a physiological picture of this phase of the life of woman. There are neurasthenic phenomena; general tiredness, feeling of internal pain, giddiness, paraesthesia, hyperaesthesia, occasionally neuralgia variously localised; vasomotor phenomena, recurrent sweats, disturbances of cardiac rhythm; unusual increase or diminution of adipose tissue; a complex of phenomena, in fact, which reveals a nutritive and functional disturbance of equilibrium

of the whole economy, of which it is not easy to specify the causes or internal conditions. It is certain, however, that these phenomena cannot depend exclusively on the nervous relations between the ovaries and the other organs; the hypothesis seems then naturally very probable that to the ovary, as well as to the testicles, must be attributed a special *internal secretion*, the cessation of which at the beginning of the menopause causes the symptomatic picture we have traced. It is, however, observed that in women of healthy constitution these abnormal phenomena are not of long duration, and disappear entirely when the climacteric period is passed, probably because there are compensations or functional substitutions, and a new and perfect equilibrium is established.

The phenomena following spaying or ablation of the ovaries in women recall perfectly those which occur at the menopause. On the effects of ovariectomy in woman we have an extensive literature, which has been collected and illustrated by Hegar (1878) and by Kehrer (1877) in special monographs. Experiments on animals have demonstrated the little importance to be attached to the nervous relations between the ovary and the other organs, and have consequently given prominence to the doctrine of internal secretion.

Knauer (1896) was the first to carry out transplantation of the ovaries in rabbits, and to observe that by it are avoided all the local and general effects which follow ovariectomy. His observations were in part confirmed by Ribbert (1898), Preobraschensky (1899), Grigorieff (1897), Rubinstein (1899), and C. Foà (1900-1901).

Of the many experiments on homoplastic transplantation of the adult ovaries in rabbits made by Knauer almost all gave negative results, as far as their function as sexual glands was concerned. However, in one ovary, three weeks after grafting, he saw the stroma and follicles still well preserved. Preobraschensky also obtained from homoplastic grafting some positive results. He found that the ovary preserved its follicles for a long time and regenerated the specific elements, but they afterwards perished and only kept their shape transiently. C. Foà, however, performing homoplastic transplantation of the *embryo* ovary to adult rabbits, observed that they took root and soon attained the structure of adult and functioning ovaries; so much so that, in one case only two months after grafting, an ovary removed from a rabbit two days old and transplanted in one eighteen months old produced ova capable of fertilisation and proceeding to pregnancy. In a second series of experiments he grafted the embryo ovary, not in the normal position, but in a part some distance from it, removing at the same time the ovaries from the rabbit operated on. One of these rabbits

became gravid only five months after the operation. Grigorieff also obtained a similar result.

In a third series of experiments Foà attempted the grafting of the embryo ovaries in male guinea-pigs under various conditions, in adult males and immature males, castrated or not at the time of grafting. In these cases also the ovaries attached themselves, and developed up to a certain point, but later on slowly and progressively underwent atrophy. Thus the male organism for some reason unknown does not constitute a medium adapted to conserve for any length of time the function of the grafted ovary, although striking root and a certain degree of development, up to the formation of Graafian follicles, are possible.

The most recent transplantations of the ovaries were attempted with success by Halban (1899-1902) both in the guinea-pig and the female baboon (*Cynocephalus*). He called attention more particularly to the fact that the arrest of development of the genital apparatus, specially of the uterus, which is the unfailing consequence of bilateral ovariectomy, does not ensue after transplantation of the two ovaries. This result excludes the hypothesis of possible nervous influences promoted by the ovary on the other organs, and is in favour of the doctrine of *internal secretion*.

We have already examined the causal relation existing between maturation and bursting of the Graafian follicle, and the periodic phenomena which occur in the uterus (*v. page 179 et seq.*). Now Born originated the hypothesis that this functional connection between the ovary and the uterus is effected by a product of the internal secretion of the *corpus luteum*, which is developed at the point of rupture of the follicle. This hypothesis was confirmed by the researches carried out under the direction of Fränkel and Cohn (1901). They noticed that spaying performed on rabbits from six to twenty-four hours after fertilisation invariably prevents the attachment to the uterus and the development of the fecundated ovum, and the same effect is produced, when instead of extirpating the ovaries, all the *corpora lutea* existing in them are cauterised with a red-hot needle. Fränkel observed also that the cauterisation of the *corpora lutea* prevented the progressive development of the ovum which had already struck root in the uterus and begun to develop. These facts demonstrate that both the planting in the uterus of the fertilised ovum and its development there are dependent on an internal secretion of the lutein cells. As these are formed after the bursting of the follicle, even when fertilisation and pregnancy do not take place, it is logical to consider that menstruation in women, or the corresponding active state of the uterine mucosa which accompanies the period of "heat" in animals, depends also on the internal secretion of the *corpora lutea*.

Lastly, Fränkel gave prominence to the fact that destruction

of the *corpora lutea* in rabbits causes lasting nutritive disturbances of the uterus, shown by retrogressive metamorphosis similar to that which is observed after bilateral ovariectomy.

As, however, the uterus is nourished and develops during the time of active growth, that is, the period which precedes ovulation and menstruation, it is necessary to admit that not only the lutein cells, but the whole of the epithelia entering into the constitution of the ovarian parenchyma, are the seat of an internal secretion which not only regulates the nutrition of the uterus, but influences that of the whole organism. Perhaps this *continuous internal secretion* of the ovarian parenchyma increases periodically, or acquires a different specific nature coincidentally with the bursting of the follicle and the development of the lutein epithelium.

This interesting subject of the continuous and periodic internal secretion of the ovary deserves to be placed in greater prominence, determining, as it possibly does, the different functional value to be attached, from the point of view of the endocrine function, to the different epithelial elements of the ovarian parenchyma.

So far we have made acquaintance with the germinal epithelium which invests the surface of the ovary, with the cells of the tubes or cords which sink from the surface to form the primary oophorous follicles, from which are developed the mature or Graafian follicles; lastly, the special lutein cells which are developed after the bursting of the follicles and constitute the essential elements of the *corpora lutea*. But we have not had an opportunity of making any reference to the so-called *interstitial cells* which are scattered in fair numbers in the supporting connective tissue stroma of the female genital glands; these cells are in all respects similar to the interstitial cells of the testicle, of which we have spoken in the preceding Chapter (*v. para. VII.*). Concerning these structures, their origin and their function, a rich literature has been formed recently.

They are large polyhedral cells, with a protoplasm rich in fat granules, and morphologically identical with the corresponding cells of the testicle. It is agreed also that they are identical with the cells which compose the *theca interna of the follicles*; many observers maintain that they are of a connective tissue nature, but many others judge them to be of an epithelial character.

According to Plüger and others they have a functional value essentially trophic in respect to the development of the ova; others, on the other hand, see in them the principal anatomical substratum of the internal secretion of the ovary. Their resemblance in morphological and chemical characters to the lutein cells, from which they differ only in their smaller size, have induced some to consider them as elements of the same kind. From the comparative histological researches carried out by Cesa-Bianchi (1907) there would appear to be an inverse development

of the two elements in different animals. In those animals in which the widely diffused interstitial gland is very greatly developed the *corpus luteum* is of modest dimensions, whereas it reaches a great development in animals in which the interstitial gland is only represented by a few scattered elements in the stroma of the ovary.

Even more interesting from our point of view as physiologists appears the fact observed by Cesa-Bianchi in hibernating animals: during their winter lethargy the interstitial glands of the ovary are poorly represented; while at the time of awakening, and during the whole of the summer, when there is the greatest sexual activity, they assume a great development. With our present knowledge, therefore, the conclusion appears to be justified, that both the elements of the interstitial glands and those of the *corpora lutea* represent the anatomical substratum of the *periodic internal secretion* of the ovary. By exclusion it appears to me that one may also provisionally admit that all the other epithelial elements of the ovary, which are continually formed and degenerate, without reaching the dignity of *mature ova* destined for the reproduction of the species, represent the substratum of the *continuous internal secretion*, which influences the nutrition and metabolism of the whole organism, and on which probably depends the development of the secondary sexual characters.

We saw that, in man, complete castration performed before puberty causes failure of development of the male secondary sexual characteristics. It is not known whether an analogous phenomenon, that is, the absence of female secondary sexual characteristics, would occur in consequence of bilateral ovariectomy, because surgeons have not had occasion to perform this operation during adolescence. Cases are not rare, however, of women who, being sterile through precocious arrest of development of the ovaries, and of all the female genital apparatus, show a marked want of external feminine characters: masculine habit and temperament, rough and deep voice, narrow hips, undeveloped mammae, stature higher than the average, and growth of hair on the face.

Bilateral ovariectomy in the treatment of various morbid conditions is an operation which has become sufficiently frequent in modern surgery. The disturbances of the general state which follow it are analogous to those of the climacteric period, and fall in great part within the domain of the nervous system. Among the most common effects of ovariectomy is *obesity*, the abnormal accumulation of adipose tissue; but according to statistics this proves true of only half the woman operated on; in others, either this effect is not noticed, or there is a pronounced opposite effect, that of *thinness*. There are many circumstances which may

influence the accumulation or loss of fat, which in not a few cases manifests itself gradually, and only becomes definite after a long lapse of time.

To appreciate in their intimate nature the material changes following bilateral ovariectomy the comparative researches carried out on the dog before and after spaying are most important. Loewy and Richter (1899) determined the absorption of oxygen, and the discharge of carbon dioxide, as a measure of the general metabolism. They found that a few weeks after spaying the intensity of the metabolism gradually diminishes until it reaches a definite minimum, when it remains constant. The diminution of the respiratory gaseous exchange reaches about 20 per cent of its initial value.

This was observed by them in cases in which after ovariectomy the weight of the body increased, as well as in those in which it diminished; in the first instances the lowering of respiratory activity is absolute, and not only relative to the weight of the body as in the second cases.

This decrease in the respiratory exchange probably depends on a diminution of the oxidation processes in the tissues, due to the want of the continuous internal secretion of the ovaries. Loewy relates that he kept a spayed bitch under observation for three years and a half, and found that the minimum value reached by the respiratory exchange remained almost constant for all this long period. He noticed also that if ovarian extract was injected under the skin of this animal, or of others similarly spayed, or the substance of the ovaries of any animal whatever was administered by the mouth, the activity of the respiratory exchange rose again to normal, or even above it. The glycerine extract of the ovary shows itself always more active than testicular extract; the first acts in castrated females as well as males, the second only in males. The attempts directed to define more exactly and isolate the *active substance* of the ovary, as that of the testicle, have not led so far to any satisfactory results.

The internal secretion of the ovaries appears also to have some relation with the material changes in the bones. Fehling, in his gynaecological clinic, had observed that the morbid process in the bones known as osteomalacia improves noticeably after ovariectomy (1895). He then ascertained the amount of lime and phosphorus eliminated by those affected, both before and after spaying, but did not find any sensible difference that would furnish an explanation of the empirical fact observed. Curatolo and Tarulli, however (1896), repeated in my laboratory the same researches on dogs, and noticed that after bilateral ovariectomy there is a diminished elimination of phosphorus, but that after injections of ovarian extract there was an appreciable increase. Neumann, in the same year, confirmed in the main particulars the observations of

Curatolo and Tarulli, but found differences so slight that no great importance could be attached to them.

The results obtained by Falk (1899) were, however, negative.

In any case we can affirm, as a general conclusion from what has been set forth, that the balance of evidence from the whole of the researches, though incomplete and fragmentary, on the *internal function of the ovary*, shows that it certainly does not consist in an effect brought about in a reflex way by means of the nervous system, but in the formation of substances chemically active, which, carried in the circulation, are capable of modifying the nutrition and metabolism of the entire organism, either in a continuous manner by the epithelial elements of the follicles and superficial epithelium of the ovarian parenchyma, or in a periodic way by the epithelial elements of the *corpora lutea* and the interstitial glands.

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CHAPTER VI

PREGNANCY—PARTURITION—PUERPERIUM

SUMMARY.—1. Segmentation of the fertilised ovum; formation of the folds of the blastodermic vesicle; process by which the ovum grafts itself on the uterine mucosa. 2. Formation of the *decidua*, *chorion*, and the *maternal and foetal placenta*. 3. Formation of the *amnion*, the *umbilical vesicle*, the *allantois* and the *umbilical cord*. 4. Gravid changes in the uterus and other organs of the genital apparatus, and functional modifications of the whole organism. 5. Mechanism of uterine contractions and the pains which occur during parturition; innervation of the uterus; the internal causes which determine parturition; the help of the abdominal pressure during the ecbolic pains; ligature of the cord, the after-birth or *secundines*. 6. The phenomena of the recovery of the parts, puerperium. Bibliography.

To complete the interesting subject of the *reproduction of the species*, it only remains for us to develop the physiological examination of the functions of maternity properly so called; these comprise the phenomena of *pregnancy*, *parturition*, the *puerperium*, and *lactation*. We have, however, discussed the last function at sufficient length in Vol. II. Chapter IX. when speaking of the secretions of the cutaneous glands and the affinity and philogenetic homology between the sebaceous and mammary glands.

As regards *pregnancy*, *parturition*, and the *puerperium*, we must in this chapter confine ourselves to physiological questions and problems, so as not to encroach upon the practical aspect, which is dealt with in books on obstetrics.

I. We saw that the fecundation of the ovum or female sexual cell by the spermatozoon or male sexual cell (v. pp. 192-9) is brought about by the conjugation of the male pronucleus with the female pronucleus; in this way a new and complete nucleus is formed, which represents the *germ* of the individual to be born. This new nucleus is called the *nucleus of segmentation*, because from it starts the development of the new being. Directly it is fertilised there commences in the ovum a rapid process of cell multiplication by *karyokinesis*: the primordial nucleus divides into two parts and the protoplasm collects round them, forming the first *spheres of segmentation* or *blastomeres*. By successive karyokinetic divisions rapidly following one another,

each blastomere divides into two, and in proportion as their number grows in geometrical progression their size diminishes, and they become compressed at the points of contact, thus becoming polyhedral. The stage thus reached is termed the *morula* or mulberry; the ovum has been transformed into a spherical mass of embryonic cells, with a rough surface (Fig. 75).

Very soon the blastomeres of the morula arrange themselves regularly at the periphery through the action of an albuminous liquid which collects in the centre of the sphere, where a cavity is formed called the *segmentation cavity*, and the morula is transformed into a vesicle constituted of a single stratum of cells called the *blastula* or *blastodermic vesicle*. At the superior pole of

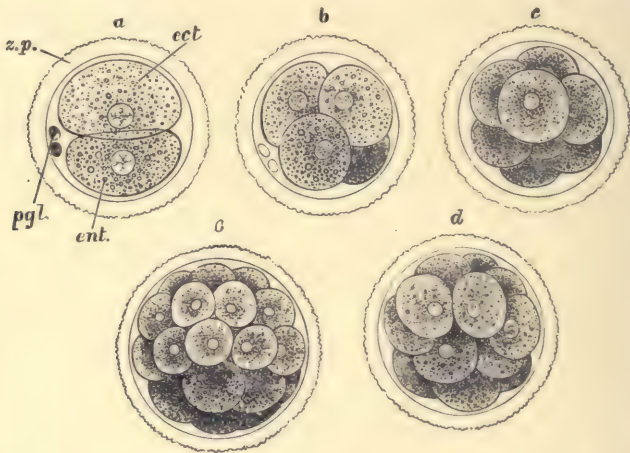


FIG. 75.—Mammalian ovum. Segmentation and formation of morula. *z.p.*, zona pellucida; *p.gl.*, polar globules.

the blastula there has remained an accumulation of cells which are more opaque than the primitive internal cellular mass of the morula; from this the body of the embryo and its membranes will be developed, and it is therefore called the *embryonic area* (Fig. 76). Through successive processes of division and cellular differentiation of the embryonic area the blastodermic vesicle very soon shows two strata of cells which constitute the two primary layers: the external layer, represented by lighter cells and called the *ectoderm*, extends from the beginning to the whole periphery of the vesicle; the internal, represented by the darker cells and called the *endoderm*, begins to develop in the embryonic area, extends gradually towards the equator, and finally reaches the inferior pole of the vesicle.

Very soon, however, between the *ectoderm* and the *endoderm*, the embryonic area begins to develop a third layer, called the

mesoderm or *mesoblast*, which in like manner gradually extends towards the equator, eventually reaching the inferior pole of the ovum.

The *mesoderm* afterwards subdivides into two layers, one superficial, which remains in contact with the *ectoderm* and is therefore called *parietal*, and the other remaining in contact with the *endoderm* and therefore termed *visceral*. The parietal layer

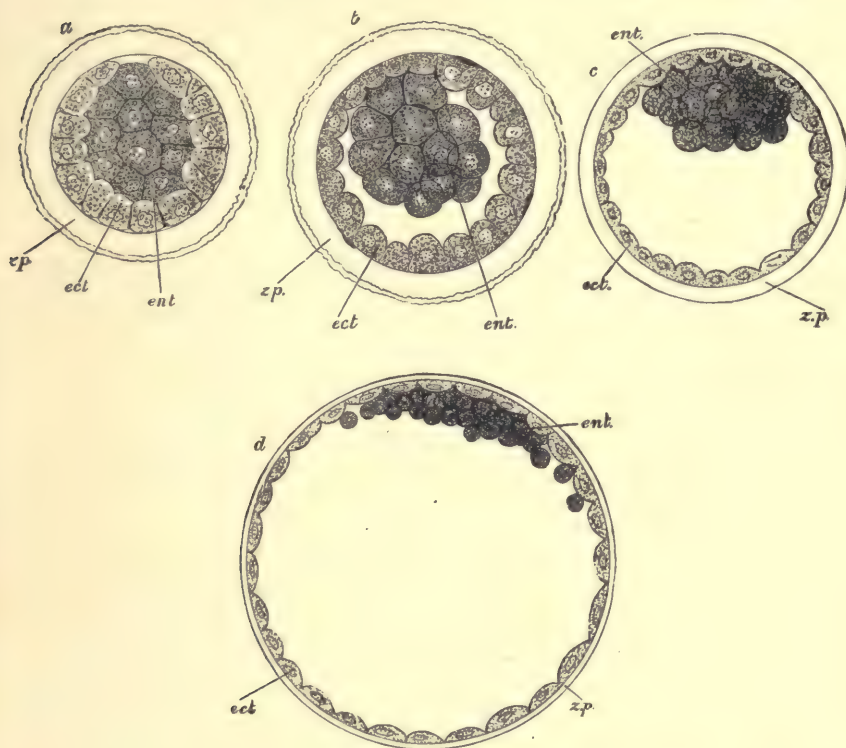


FIG. 76.—Sections of mammalian ovum to show the formation of blastocyst. *z.p.*, zona pellucida; *ect.*, peripheral stratum; *ent.*, internal cellular mass, *embryonic bud*.

forms the so-called *somatopleure*, the visceral layer constitutes the *splanchnopleure*. The term *coelom* or *body-cavity* is applied to the space included within these layers. The division of the *mesoderm* into two layers takes place throughout the whole blastodermic vesicle; it begins in the embryonic area and proceeds towards the inferior pole of the ovum as far as the extension of the *mesoderm*. The *coelom* may then be distinguished as internal, or intra-embryonic, and external, or extra-embryonic. Before, however, we examine the successive developments of the ovum,

we will pause to explain the manner in which the ovum grafts itself in the uterine mucosa with which it has come into contact.

According to Minot, the ovum reaches the uterus on the eighth day after fecundation, when it is about 0.2 mm. in diameter, has already undergone the process of segmentation and reached the morula stage. According to the observations of von Spee, the ovum of the guinea-pig, when it arrives in the uterine cavity, provokes therein a marked hypertrophy of the epithelial covering; a breach is made at the point of contact, and the ovum sinks into a small depression formed in the sub-epithelial connective tissue (Fig. 77).

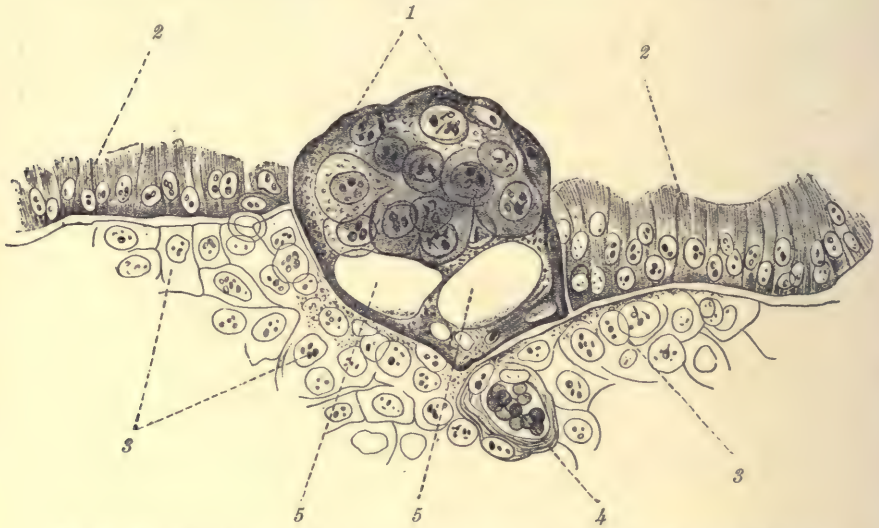


FIG. 77.—Planting of ovum of guinea-pig in uterine mucosa. (von Spee.) The ovum (1) passes through the uterine epithelium; 2, sinks through the opening in the epithelium into a depression hollowed out in the sub-epithelial connective tissue; 3, connective tissue cells; 4, capillary vessel; 5, cavity within ovum formed by cells of segmentation, both large and round.

We do not as yet possess any actual observation of the first stages of the human ovum. The earliest studied by Reichert was twelve to fourteen days old; the *chorion*, the most external membrane of the ovum in the course of development, was already fairly well developed, was provided with villusities on a circular zone, and contained a rough outline of the embryo (Fig. 78).

As to the way in which the human ovum grafts itself on the uterus we have only Peter's observations made on a woman who had committed suicide a few days after the cessation of menstruation. The ovum looked like a prominence about the size of a hemp-seed on the uterine mucosa. The posterior wall of the mucosa was considerably thickened. The grafting had taken place in the space between two glands. At the point

of perforation the epithelium was wanting, and there was in its place a sort of plug formed by a fibro-sanguineous network. The ovum showed an outline of the embryo like that found by Reichert and a *chorion* provided with villousities. The mucous membrane round the chorion showed dilated capillary vessels among the villi (Fig. 79).

The excavation in which the ovum had settled was clearly the result of a process of softening of the mucosa and cytolysis of the sub-epithelial connective tissue. Is this due to the irritative and cytolytic action of the growing epithelial cells of the chorion, so that we can affirm with Sharpey and Bumm that it is the ovum in process of development which hollows out its own bed in the thickness of the uterine mucosa? This does not seem probable, for even if we admit the theory, it is not easy to explain why the non-fecundated ovum is not capable of acting in the same way on

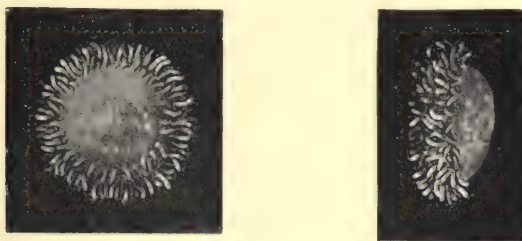


FIG. 78.—Ovum found by Reichart in the uterus of a woman who had committed suicide. Magnified to four times natural size. (Front and side view.)

the uterine mucosa, and the researches of Fränkel and Kohn have proved that the grafting of the fertilised ovum in the uterus and its further development are due to the *internal secretion* of the cells of the *corpora lutea*. Sfameni (1904) definitely states that the ovum in process of attachment does not exercise any destructive action on the uterine mucosa, but merely stimulates it to proliferate; this results in the wrapping of the ovum in a fold of maternal tissue, called the decidua. The most recent researches of Leo Loeb (1910) have proved on the other hand that when the uterine mucosa has been made sensitive by the internal secretion of the lutein cells, the simple mechanical action of the ovum is sufficient to set in motion the whole process through which the formation of the decidua, the attachment of the ovum, and the constitution of the placenta are brought about. He succeeded indeed in producing these processes artificially in the uterus by inserting in it chemically inert foreign bodies, thin capillary glass tubes, for instance, introduced through the cervix.

II. In the preceding chapter, when treating of the relations between ovulation and menstruation, we mentioned the changes

undergone by the uterine mucosa, by means of which the so-called *catamenial decidua* is formed. We also described the *haemorrhagic*

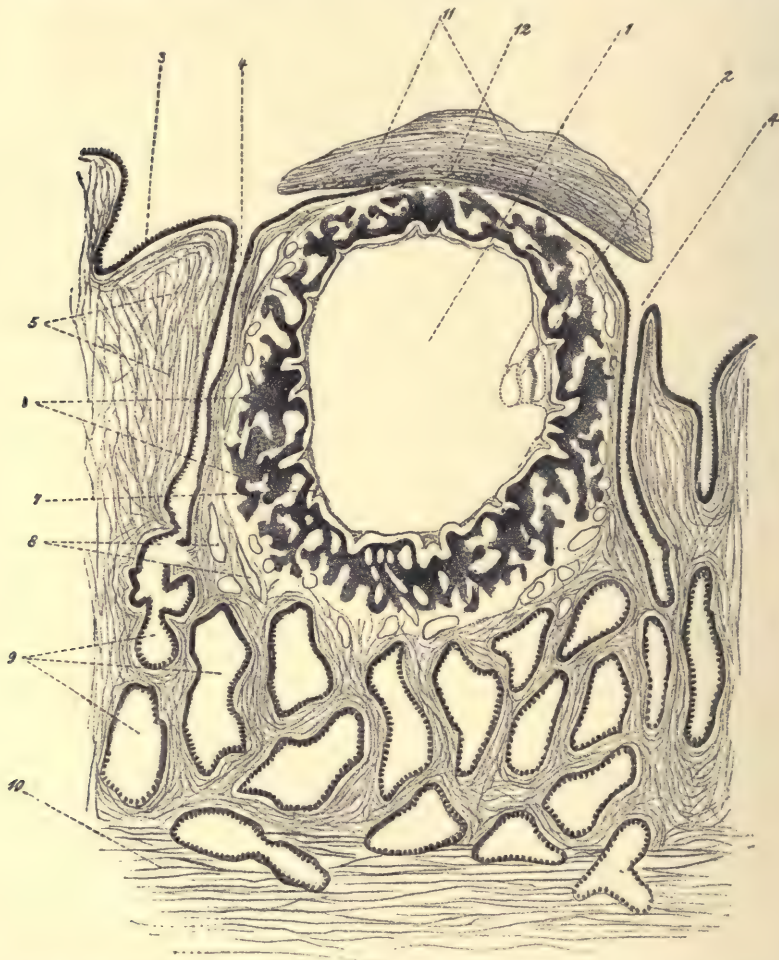


FIG. 79.—The earliest stage known of the process of fixation of the human ovum. (Peter.)
1, ovum; 2, outline of embryo: uterine epithelium wanting at point perforated by ovum; 3, openings of glands; 4, openings of glands; 5, connective tissue stroma of the mucosa; 6, proliferated ectoderm of ovum (trophoblast) with initial formation of villosities and extension of syncytium, immersed in a network of sanguineous lacunae, continuous with the capillaries surrounding the ovum; 7, projection of the mesoderm; 8, sections of glands; 9, sections of glands; 10, muscularis; 11, network of blood and fibrin, covering the opening made by ovum.

and *degenerative* process which takes place in the mucosa when the ovum arrives in the uterine cavity without being fertilised.

We must now see what occurs in the uterine mucosa when the

fertilised ovum which has reached the *morula* stage has grafted itself successfully in the thickness of this mucosa. In these cases the *menstrual decidua* does not degenerate, but is transformed into the *decidua gravidica* by a process of further development. Diagram 80 gives a fair idea of the changes undergone by the thickness of the uterine mucosa as a whole and in each of its layers.

In the part in which the ovum is grafted the mucosa grows rapidly and forms a capsule-like covering round the ovum which, resembling a mucous polyp, projects into the cavity of the uterus (Fig. 81). At this stage the part on which the ovum is grafted is called the *basal decidua* or *decidua serotina*; that which enfolds the ovum is termed the *capsular* or *decidua reflexa*; all the rest of the mucosa of the uterine cavity being called the *decidua vera* or *parietalis*. The basal decidua is interposed between the ovum and the muscular tissue of the uterus; and since it is destined to form the maternal portion of the placenta, it is also called the *decidua placentalis*.

At the end of the second month of pregnancy the ovum is almost the size of a hen's egg, and there is a space of from 1 to 2 cm. between the parietal and the reflex decidua. The reflex decidua becomes steadily thinner, while the parietal and the placental become more hypertrophic.

During the following months of gestation, the progressive increase in volume of the ovum causes retrogressive processes in the uterine mucosa, and a gradual approach of the decidua reflexa to the decidua vera,

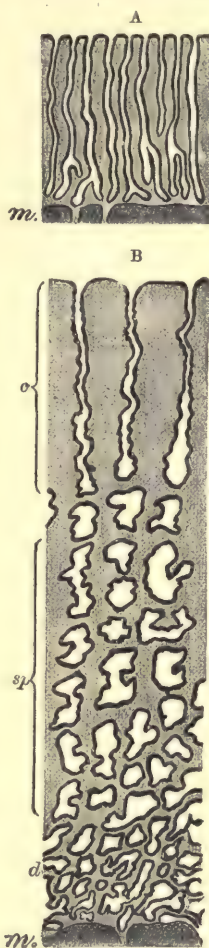


FIG. 80.—Schematic sections of uterine mucosa showing the changes undergone by the glands when the mucosa is transformed into the decidua of pregnancy. (Kundrat and Engelmann.) A, mucosa of non-gravid uterus; m., tunica muscularis. B, decidua parietalis at beginning of pregnancy; c., stratum compactum; sp., superficial part of stratum spongiosum; d., deep part of stratum spongiosum; m., tunica muscularis of uterus.

so that at the fifth month they come into contact and become coherent, with the disappearance of all trace whatsoever of the free cavity of the uterus (Fig. 83).

During the last five lunar months up to the time of parturition no further modifications in the relations of the membranes of the ovum to the uterus are to be noted. They follow and accompany the enlargement of the cavity of the ovum. The progressive growth of the uterus is not, however, uniform at all points, but is

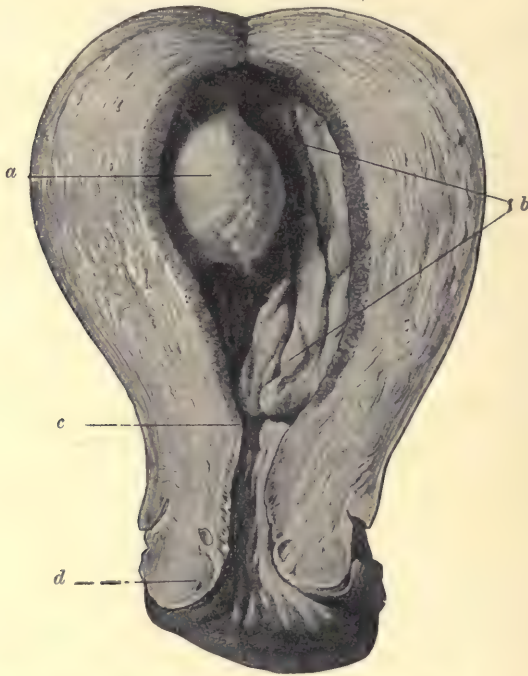


FIG. 81.—Uterus with ovum at fourth week of pregnancy. Natural size. *a*, ovum covered with decidua reflexa; *b*, decidua vera; *c*, internal orifice; *d*, external orifice.

much greater in the lower half, so that the uterus, which is almost round at the fifth month, assumes an elongated form at the end of pregnancy or the tenth lunar month, and the lower margin of the placenta is withdrawn more than four fingers' width from the internal opening of the uterus, as may be seen by comparing Fig. 84 with the preceding illustration.

We must now examine the ovum so as to be better able to explain the relations between it and the decidua gravidica, which is destined to become the *placenta*.

During the first stages of development the *chorion*, which is

furnished with numerous ramified villi, develops from the ectoderm of the germinal vesicle (Fig. 78). Each villus is formed of vascular connective tissue, covered with a protoplasmic stratum, with nuclei in lines without distinct cellular boundaries, called the *syncytium* of the chorion, covering an underlying stratum of

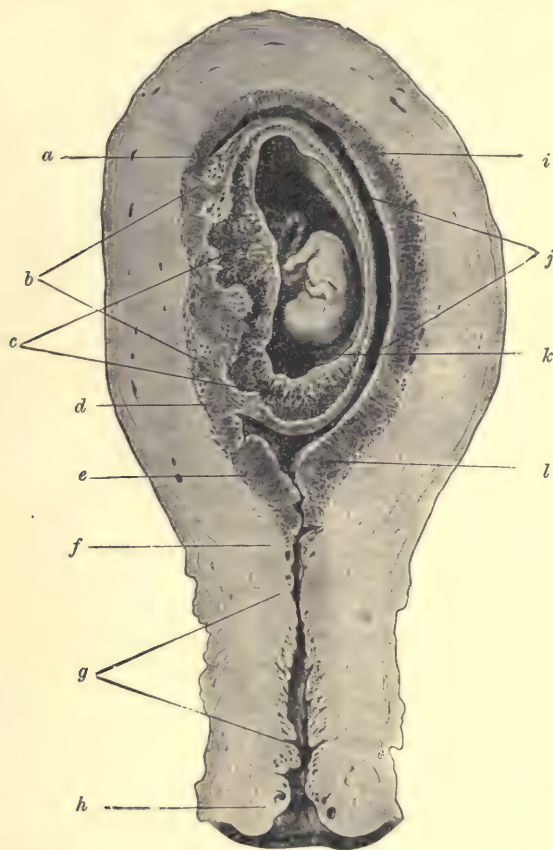


FIG. 82.—Uterus with ovum at the end of the second month of gestation. Longitudinal section. Natural size. (From a preparation at the Obstetrical Clinic at Bale.) *a*, boundary between decidua vera and reflexa; *b*, decidua serotina; *c*, chorion frondosum; *d*, boundary between decidua vera and reflexa; *e*, decidua vera; *f*, internal orifice; *g*, cervix; *h*, external orifice; *i*, decidua vera; *j*, cavity of uterus; *k*, cavity of ovum; *l*, decidua vera.

clearly defined cells called the *cellular stratum of Langhans* (Fig. 85). At the third month a very distinct difference begins to be seen between the chorionic villousities of the part corresponding to the capsular region and those of the part standing in relation to the basal or placental decidua. In the former the villi cease to develop, becoming scarcer, smaller, and simpler, until the

chorion assumes the appearance of a smooth membrane (*chorion laeve*); in the region of the placental decidua, on the contrary, the villousities become hypertrophic and longer, ramify and multiply (*chorion frondosum*). This flourishing vegetation of the chorion



FIG. 83.—Gravid uterus at five months. Longitudinal section. Half natural size. (From a preparation of the Obstetrical Clinic at Bale.) *a*, decidua vera; *b*, chorion and amnion; *c*, marginal substance of placenta; *d*, internal orifice; *e*, external orifice; *f*, vagina.

in the seat of the placenta is shown in Fig. 82, but is more obvious in Figs. 86, 87, and 88.

The origin of the epithelial covering of the villus is at present a disputed point. The syncytium and the cellular stratum of Langhans represent a single element, inasmuch as the syncytium may be transformed into the cells of Langhans and *vice versa*.

Consequently these elements cannot be considered as separate in origin, as was thought by many in times past, but a common origin must be sought for them both.

It is almost universally admitted that the syncytium and the

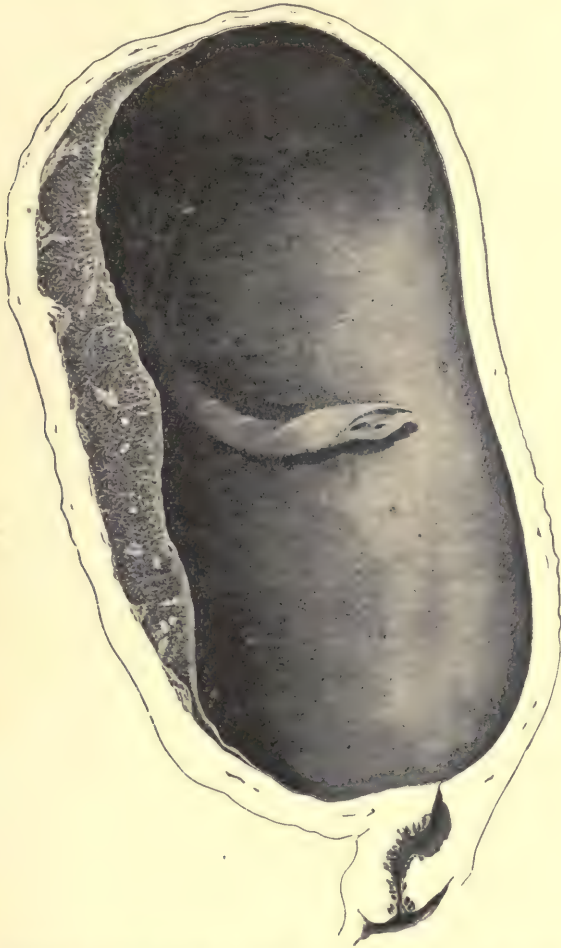


FIG. 84.—Gravid uterus at the tenth month. Longitudinal section. Half natural size.
(From a preparation at the Obstetrical Clinic at Bâle.)

cells of Langhans proceed from the foetal ectoderm. Sfameni alone, going back to Ercolani's theory, is of the opinion that they are derived from the decidua, and thus are of maternal origin, and that the foetal ectoderm in woman and the higher mammals is destined to disappear, as was shown by Ercolani in his numerous

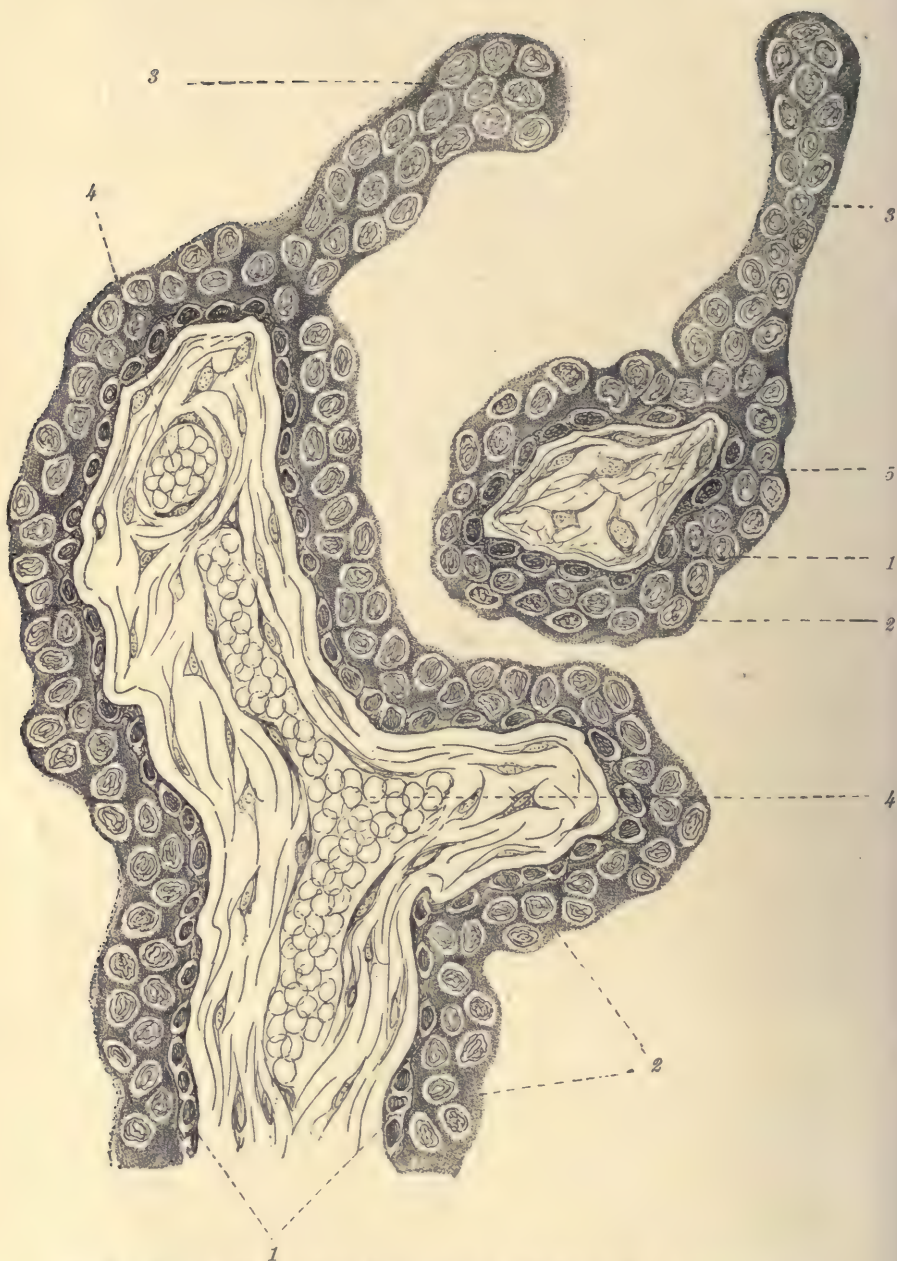
*A**B*

FIG. 85.—Chorionic villi of an ovum of five weeks. *A*, longitudinal section; *B*, transverse section. Greatly magnified. 1, cellular stratum of Langhans; 2, syncytium; 3, processes of syncytium; 4, foetal capillary vessels; 5, connective tissue of villus (stroma).

works on placentation. Sfameni disagrees with Ercolani on one point only, the origin of the decidua, which he derives from the proliferation of the epithelium, whereas Ercolani derives it from the connective tissue of the uterine mucosa. The layer of tissue which immediately surrounds the ovum settled in the mucosa of the uterus has received from modern writers the name *trophoblast*, and from it the syncytium and Langhans's stratum of the chorionic villi are rightly considered to arise. This layer is, according to Sfameni, merely decidua, which, owing to the fact that it is in immediate contact with the ovum, shows greater

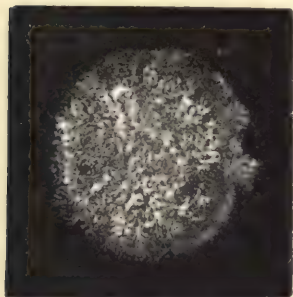


FIG. 86.—Ovum of about four weeks.



FIG. 87.—Ovum at the end of two months.



FIG. 88.—Ovum in the course of the third month.

activity in proliferation, because to it is assigned the task of enveloping the ovum.

The blood-vessels in the region of the *chorion laeve* become obliterated; in the region of the *chorion frondosum*, on the contrary, they develop at the same rate as the proliferations of the villi, and extend to the smallest offshoots thereof in the form of an arterial capillary, coil-like network which gives rise to a small vein (Fig. 89). The villi of the *chorion frondosum*, which are rich in vessels, may be compared from the physiological point of view

to the roots of a plant which spread and multiply in suitable nutritious soil, the soil being represented by the hypertrophic placental decidua. These much ramified and vascularised villi do not emerge uniformly from the placental chorion, but appear in clump-like groups or tufts called *cotyledons*. On the other hand, through proliferation of the decidual tissue, more or less developed



FIG. 89.—Terminal portion of trunk of villi of a placenta at term: injection of the arteries (red); of the veins (blue). (After Bumm.)

septa, defining as many small spaces, are found between the cotyledons.

It is thought by many that a solid adhesion of the surface of the villi to that of the decidua occurs only in the trunk and main branches of the villi (*roots of attachment*), the larger number of the ramifications of the villi terminating freely in a system of *intervillous spaces* found between the chorion and the decidua (*free prolongations of the villi*). In a few weeks the maternal blood penetrates into this system of intervillous spaces as a

consequence of the rupture of the superficial vessels of the compact stratum of the decidua.

Other observers, on the contrary, are of opinion that perfect cohesion, leaving no interstices of any kind, is established from the first between the surface of the chorion and that of the decidua. At successive stages of the evolutionary process, ample vascular sinuses are formed in the compact stratum of the decidua, causing it to assume the structure of cavernous tissue: the chorionic villi are covered by a sheath of endothelium, which

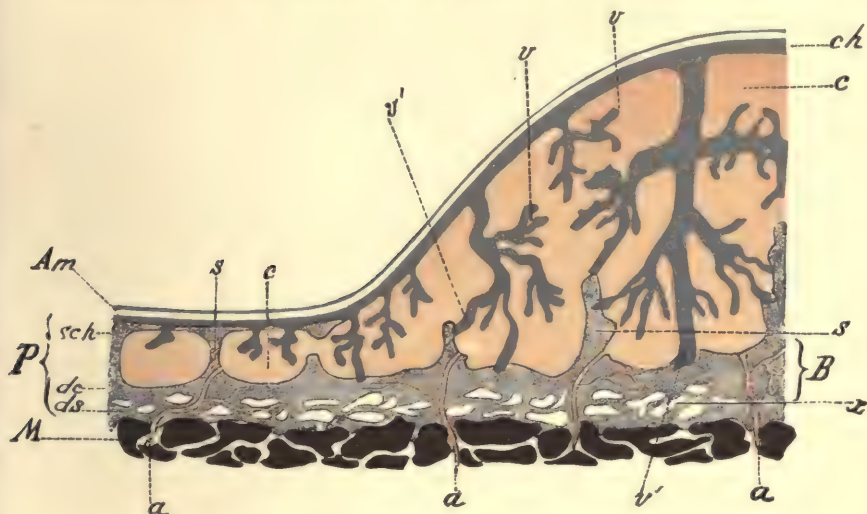


FIG. 90.—Structure of the placenta; diagram after Leopold; edge of the placenta on the left. *P*, decidua placentalis; *ds*, stratum spongiosum of the decidua; *dc*, stratum compactum of the decidua; *sch*, subchorionic obturator ring; *ss*, decidual intercotyledonal septa; *s*, line along which the splitting of the decidua and hence the detachment of the placenta in parturition is effected; *B*, vascular layer of Winkler; *ch*, chorion with chorionic villi; *v*, free prolongation of villus; *v'*, adherent prolongation of villus; *Am*, amnion; *a*, uterine artery opening into the intervillous spaces, *c*.

represents the wall of the placental sinuses, hence the appearance of intervillous spaces filled with blood (Fig. 90).

Whatever may be the truth with regard to this debated point, it is certain that an intimate relation is established between the villi of the chorion and the lacunae in which the maternal blood circulates. This relation is the fundamental condition in the development of the ovum by means of the exchange of the nutritive materials and gases of respiration which are indispensable to the foetus, without any intermingling of maternal with foetal blood taking place, as was believed in ancient times. When the placenta is completely developed, it presents the appearance of a circular or oval disk having a diameter of 13-20 cms. and weighing on an average 500-600 grms. This estimate Sfameni



FIG. 91.—Human placenta: foetal surface, covered by the amnion. (Chiarugi.) *f*, umbilical cord; *m*, membrane of the ovum continuous with the circumference of the placenta.

considers, however, to be erroneous, because in the weight of the placenta that of the membranes and umbilical cord is wrongly

included, as is also that of the clots of blood adhering to the after-birth. Sfameni estimates the weight of the maternal placenta at 408 grms. and that of the two other parts of which the secundines are composed—the umbilical cord and the membranes—at 33 and 49 grms. respectively. The proportion between the weight of the placenta and that of the foetus is therefore not 1:6-7, but 1:7-8.



FIG. 92.—Human placenta, uterine surface. (Chiarugi.) *c*, a cotyledon; *f*, umbilical cord; *m*, membrane of ovum continuous with the circumference of the placenta.

It is much debated among obstetricians whether causal relations in the development of mass exist between the foetus and the placenta, that is, whether the foetus regulates the development of the placenta according to its own requirements, or whether, on the contrary, a greater development of the placenta determines an increased development of the foetus. The statistics of Pozzi and Brizio would seem to bear out the latter view. Sfameni on the other hand has succeeded in proving the fallacy of the calculations

of these writers, and in showing by his own investigations that the foetus does not regulate the development of the placenta or the placenta that of the foetus, but that all the different parts of the ovum (foetus, placenta, membranes, umbilical cord, amniotic fluid) are normally mutually related as regards their development, in the sense that when one part of the ovum is more highly developed, all the others will be proportionately so. From his own observations of the relations between the weight of the placenta and that of the foetus, Sfameni came to the conclusion that the heavier placenta supplies the corresponding foetus with an amount of nutritive material smaller in proportion than that supplied by the smaller placenta.

The placenta has a spongy consistence and is dark grey in colour. The *foetal surface* is concave, smooth, and covered with a thin transparent membrane called the *amnion*; in it are found the ramifications of the placental vessels converging towards the umbilical cord, which is excentrically attached (Fig. 91). The *uterine surface* is convex, irregular, and sanguineous owing to the lacerations caused by detachment, and is divided into lobes or cotyledons (Fig. 92). On its circumference the placenta is continuous with the parietal decidua.

III. The way in which the embryonic membranes arise in the higher animals and in man differs from that which we know to be the case in the sauropsida and lower mammals, in which it is accomplished by means of a very well-known and somewhat simple mechanism.

At an early stage of development furrows (*limiting sulci* of

FIG. 93.—Diagrams showing the formation of the embryonic adjuncts in a mammal. *A, B, C*, transverse sections through axis of the embryonic area. *D, E, F, G, H*, sagittal median sections. The ectoderm is coloured red, the mesoderm black, the endoderm blue. The body of the embryo with the exception of the surface is indicated by a uniform grey. The cephalic extremity of the embryo is towards the right. *a*, amnion; *ae*, embryonic area; *al*, allantois; *ap*, amniotic fold; *c*, body of the embryo; *ce*, external coelom; *ch*, chorion; *chp*, chorion in the region where the placenta will be developed; *i*, intestine; *o*, point of junction of the amniotic folds; *s*, serous covering; *vo*, umbilical vesicle; ***, mouth; ****, anus.

A, the embryonic area is differentiated; the endoderm is confined to the upper segment of the ovum.

B, the endoderm has spread to the lower pole; the mesoderm has appeared in the region of the embryonic area.

C, the mesoderm has spread to the equator of the ovum and the coelom has formed within it, both in the embryonic area and outside it; the amniotic folds rise; the umbilical vesicle begins to be distinguishable.

D, the amniotic folds have grown, but have not yet met; the intestine communicates freely with the umbilical vesicle.

E, the amniotic folds have met, the amniotic cavity has closed; the umbilical vesicle has shrunk and, owing to the extension of the coelom, has become more detached from the ectoderm; the allantois is roughly outlined.

F, the serous covering is complete; it has become detached from the amnion and umbilical vesicle and has developed villi; the umbilical vesicle in its shrunken state is free in the coelom; the alimentary canal has opened at its two extremities, forming the mouth and the anus; the allantois has developed.

G, the umbilical vesicle has become still smaller and its peduncle narrower; the allantois with its vessels has joined the serous covering, which becomes the chorion, and its mesoderm penetrates into the chorionic villi.

H, the amniotic cavity has become larger and the amnion is about to adhere to the inner side of the chorion; the umbilical vesicle and the allantois are much smaller and their peduncles have become long and thin; the villi of the chorion have extended to the whole membrane and have grown, especially in the zone which corresponds to the insertion of the allantois, where the placenta will develop later on.

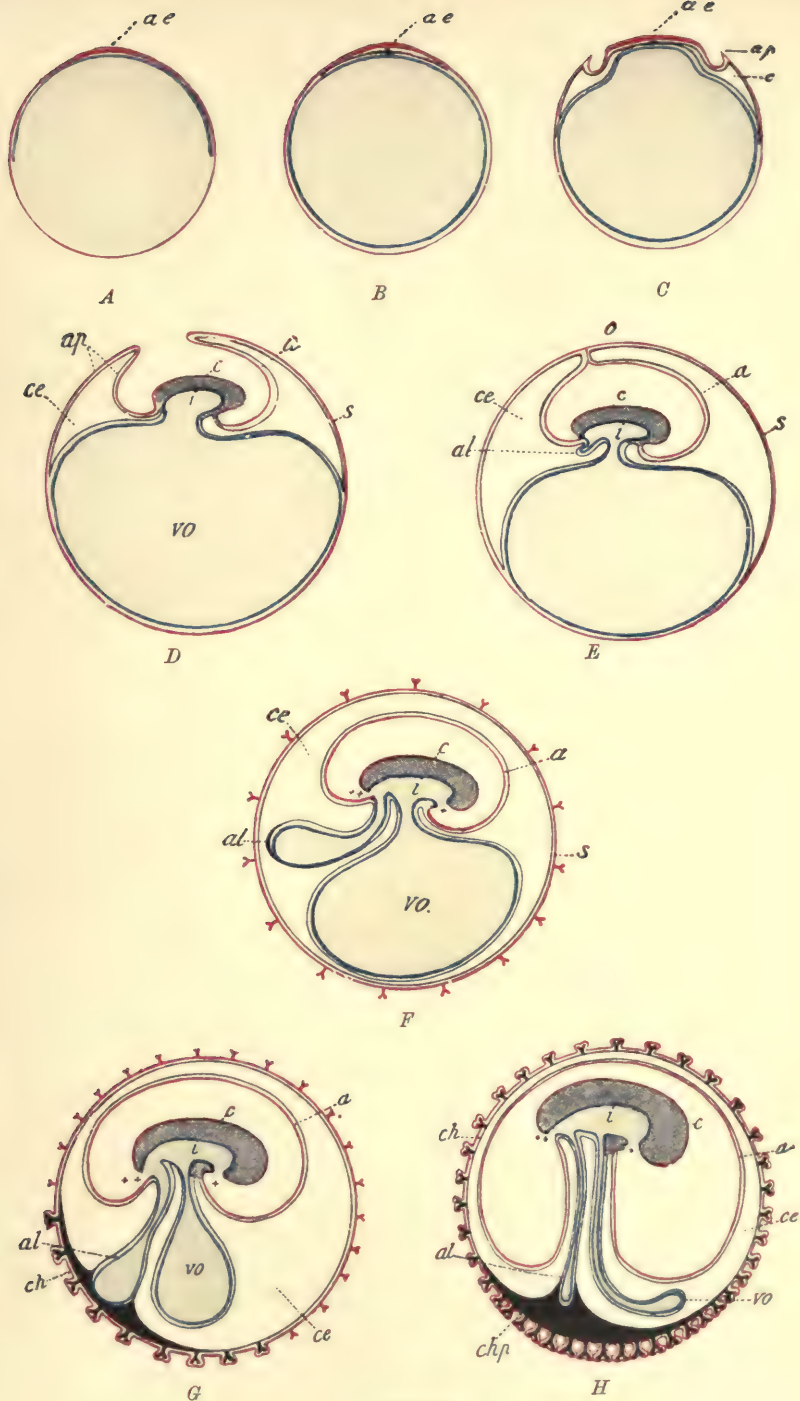


FIG. 98.

His), well marked in the anterior, lateral, and posterior parts, appear in the embryonic region. When these furrows increase in size and join each other, the embryo appears considerably raised on the blastoderm and surrounded by a single, continuous, and ellipsoidal furrow (Fig. 93, *A, B, C*). Beyond this limiting furrow the blastoderm forms a fold (*amniotic fold*); the layers taking part in the formation of this fold are the *ectoderm* and the *somatopleure*, which together are designated the *somatic lamina*, as distinguished from the *splanchnic lamina*, formed by the union of the *splanchnopleure* and the *endoderm*. The splanchnic lamina does not take part in the raising of the amniotic fold, but remains adherent to the vitelline mass which is gradually enfolded so as to form the *vitelline sac* or *umbilical vesicle*. Between the two laminae—the somatic and the splanchnic—is the cavity of the *coelom* or *pleuro-peritoneal* cavity, which becomes gradually larger at the point where the somatic lamina rises into the amniotic fold. The zone corresponding to the limiting sulcus, which is called the *umbilical region*, marks the boundary between the intra-embryonic portion (*internal coelom*) and the extra- or para-embryonic portion (*external coelom*) of the coelomatic cavity, from which the *allantois* grows later on.

The amniotic folds expand towards the back of the embryo, where, shortly before meeting, they form the so-called *amniotic orifice*, which, however, soon disappears, because the folds, when they meet, become fused and the amniotic cavity is completely closed. The fusion of the amniotic folds brings about the simultaneous formation of two embryonic membranes, which are distinct and detached: the *chorion* or serous capsule or membrane of von Baer, and the *amnion* (*F*).

The *serous membrane* or *chorion* is covered externally by the *ectoderm* and internally by the *mesoderm*. On the external surface of the chorion the *chorionic villi* are soon formed, as we have already seen.

In distinction to the *chorion*, the *amnion* is covered internally by the *ectoderm*, and externally by the *mesoderm*, in which blood-vessels and muscular fibres very soon develop. The cavity of the amnion fills with amniotic fluid, in which the embryo floats and is rocked by the rhythmic contractions of the muscular fibres of the walls of the amnion itself.

Whilst the amnion and the chorion are undergoing the changes we have described, a hollow diverticulum, covered with mesoderm, is formed on the ventral wall of the caudal portion of the intestines, and forces its way into the external coelom in the form of a vesicle and grows extremely rapidly: this vesicle, which is called the *allantois*, very soon reaches the chorion; the two mesodermic surfaces approach one another and become closely adherent, forming, as it were, a single membrane, to which the

name *allanto-chorion* has been given (*G*). The close relation is effected chiefly by connective tissue and by the intra-embryonic blood-vessels, which by means of the mesodermic covering of the allantois are connected with those developed in the internal surface of the chorion and the villi. Thus, while the chorion on the one side comes into relation with the maternal parts and on the other keeps at a distance from the embryo, the allantois, in its capacity of intermediary, renews the relations between the embryo and the chorion. Such relations may be more or less extensive, so much so that some observers on this account have divided mammals into *macro-*, *meso-* and *micro-allantoids*. In the region of distribution of the allantois the placenta is formed.

We have seen that the splanchnic lamina does not take part in the formation of the amniotic fold; it gradually envelops the vitelline substance, while from its mesodermic covering (the splanchnopleure) are developed the blood-vessels which are to help in the absorption of the vitellus. When the splanchnic lamina has completely enfolded the vitelline substance, the result is the formation of the *vitelline sac* or *umbilical vesicle*, which only occasionally enters into such intimate relations with the chorion as to form an *omphalo-chorion*. As a rule the umbilical vesicle gradually becomes smaller owing to the continuous absorption of the deutoplasm it contains (*H*).

Whereas in the sauropsida and lower mammals the formation of the embryonic membranes is effected in the way we have already briefly described, in the primates and in man development follows a different course. In this diverse procedure we see not a *process of abbreviation*—to quote a morphological expression which has no definite physiological value—but rather, as Ruffini maintains, one by which the tissues which serve to establish the relation between the product of conception and the maternal parts develop more and more rapidly as we rise in the zoological scale.

In order to understand aright the formation of the membranes in the human species, we must start from the blastodermic vesicle or blastocyst. We have already seen that a cumulus of internal cells, called from its purpose the *embryonic bud* or germ, is attached to the upper pole of the blastoderm (Fig. 76), and very shortly a series of flattened cells, arranged in a single layer, is distinguishable below the embryonic bud; this cellular portion is either arranged against the wall of the blastocyst, thus doubling it, or—as is the case of the primates and our own species—is confined to a small vesicle below the embryonic bud. Meanwhile a cavity filled with fluid appears inside this bud, and the cells, without becoming detached from the wall of the blastocyst, are arranged inside this cavity. Thus the embryonic bud is eventually transformed into a vesicle.

The upper vesicle surrounded by ectodermic cells is the *amniotic vesicle*; the lower one surrounded by endodermic cells is the *umbilical vesicle*. The region of contact between the two vesicles is the *embryonic area*, in which the cells are distinguished by their cylindrical shape (Figs. 94 and 95).

In the young human ova described by Peter, von Spee, and C. Giacomini, which were from nine to twelve days old, the mesoderm was already easily recognisable. It not only surrounded the two vesicles (splanchnopleure), but also covered the internal surface of the chorion (somatopleure); further, and this is of the greatest importance, a cord of mesoblast connects the embryonic formations with the internal surface of the chorion forming the

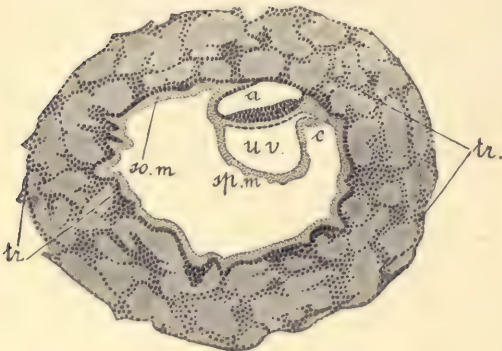


FIG. 94.

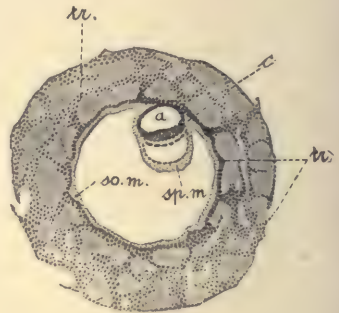


FIG. 95.

FIGS. 94 and 95.—Diagrammatic longitudinal sections of two stages of development of the primitive blastodermic vesicle of man and of the anthropoid ape, reconstructed by Hubrecht from the drawings of Selenka and Peter. *tr.*, trophoblast; *a*, amniotic vesicle; *uv.*, umbilical vesicle (between the two vesicles is the area of the *embryonic bud*); *so.m.*, *sp.m.*, somatic and splanchnic mesoblast bounding the coelomic cavity; *c*, abdominal peduncle of *His*, in the thickness of which can be distinguished a diverticulum of the umbilical vesicle which will become the allantois.

abdominal peduncle of His, as may be observed in the accompanying diagram of Hubrecht. In these very young ova there is a short diverticulum of the umbilical vesicle corresponding with the attachment of the abdominal peduncle, which is almost completely traversed by it; this diverticulum is the *allantois*.

In the human ovum of this early period in which, according to von Spee, the embryo is in the condition of the *primitive streak*, the embryonic membranes are already in existence and readily recognisable.

The *amnion*, which is formed in an entirely different way from that which we saw to be the case in the sauropsida and lower mammals, forms the upper vesicle, which is the nearest to the internal surface of the chorion.

The *umbilical vesicle*, which is already entirely closed by its

endodermic layer, forms the lower vesicle, adhering in great part to the amniotic vesicle and also to the internal surface of the chorion by means of the abdominal peduncle.

The *allantois*, which is already well marked, although a caudal intestine is not yet distinguishable, is never free in the para-embryonic body-cavity; it always passes inside the abdominal peduncle.

The *chorion*, which is derived from the original peripheral layer of the blastocyst, is already provided with villi. Its large cavity (cavity of the chorion or outer coelom or para- or extra-embryonic cavity) contains the *magma reticularis* of *Velpeau*, which also surrounds the embryonic formations.

The successive transformations undergone by the membranes of the human ovum are easily understood. The allantois, which also acts as a urinary sac, extends rapidly over the whole of that region of the chorion in which the discoidal placenta is being formed. The essential part of this process pertains, not to the epithelium of the allantois (endoderm), but to the blood-vessels which it brings from the body of the embryo to the chorionic villi. Its peduncle and its vessels, which in the first stages of embryonic life are contained in the abdominal peduncle, are seen later on to form part of the elements constituting the *umbilical cord*. At birth the extra-embryonic portion of this cord is lost, while the intra-embryonic portion continues to be of use as the *urachus* and *urinary bladder*.

We have already spoken of the transformations of the chorion.

The *umbilical vesicle* or *vitelline sac*, which originally rested on a large base after the manner of a sessile tumour on the ventral face of the body of the embryo, gradually becomes pedunculated (Figs. 96 and 97). There is a period of embryonic life in which this membrane lies unattached in the *magma reticularis* of the *external coelom*. Its peduncle or omphalo-mesenteric canal is later included in the umbilical cord, its swollen extremity lying under the amnion a little to one side of the point of union of the umbilical cord and the placenta; at birth it disappears with the after-birth. It is but seldom that in the intestine of the adult man a remnant of the omphalo-mesenteric canal is found in the form of the *diverticulum of Meckel* in the lower part of the ileum, a little above the ileo-caecal valve.

The changes undergone by the amnion must be specially studied with reference to the formation of the umbilical cord which is first indicated by the abdominal peduncle. This peduncle, when the body of the embryo is already formed (fifteen to eighteen days), is situated on the dorso-caudal side of the embryonic formation and the amnion (Fig. 96). Up to this period the abdominal peduncle contains only the allantoic canal and the allantoic or

umbilical vessels. Later the cavity of the amnion dilates with increasing rapidity; the umbilical vesicle becomes smaller; from being sessile it becomes pedunculated and consequently the line of attachment of the amnion becomes more restricted. The body



FIG. 96.—Human ovum of fifteen to eighteen days (according to Costa). The cavity of the chorion is open to show the embryo, 0.5 mm. long, and its adjuncts. *ch*, chorion; *v.ch.*, chorionic villi; *a*, amnion; *p*, abdominal peduncle; *v.o.*, umbilical vesicle.

of the embryo changes in shape as it grows; from being almost pisciform with a dorso-caudal curvature, it very soon assumes the form of a C (Fig. 98). As the result of all these changes the abdominal peduncle (with the allantoid canal and the umbilical vessels) approaches and lies on the omphalo-mesenteric canal

with its vessels, so that all these elements are found united on the ventral side of the embryo (Fig. 97). The amnion meanwhile continues to dilate and encloses the abdominal peduncle from the dorsal to the ventral surface, converting it first into a conduit and then into a closed canal, the interior of which forms a diverticulum of the coelomic cavity, included in the cord by being thus hemmed in. This canal contains the peduncle of the umbilical vesicle or omphalo-mesenteric canal with the vessels of the same name (Fig. 99).

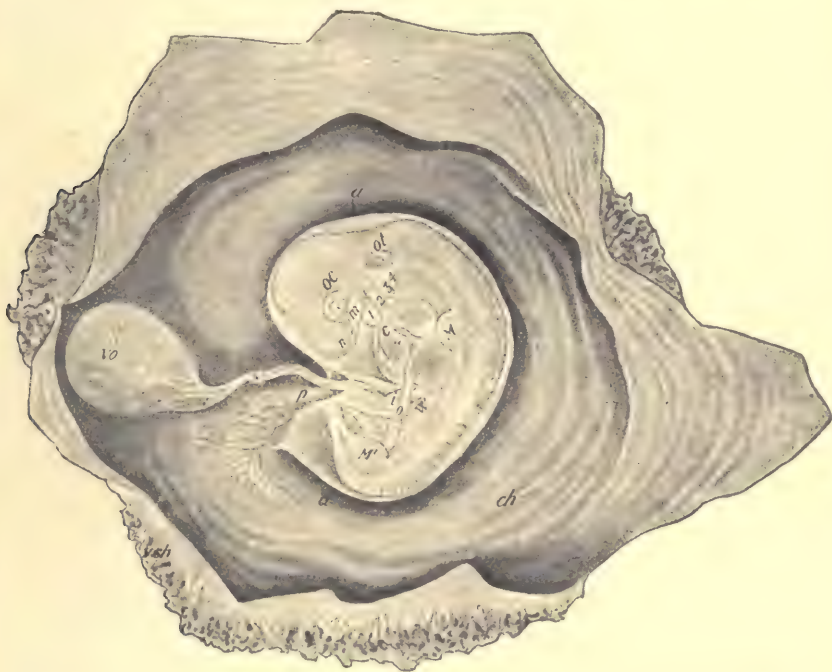


FIG. 97.—Human ovum of fifteen to eighteen days (according to Costa). The cavity of the chorion is open to show the embryo, 0.9 mm. long, and its adjuncts. *ch*, chorion; *v.ch*, chorionic villi; *a*, amnion; *v.o*, umbilical vesicle; *i*, intestine; *p*, abdominal peduncle; *o*, umbilical veins.

We may therefore say that the umbilical cord is formed of the old elements of the abdominal peduncle (mesenchyme, allantoid canal and umbilical vessels) with the addition of the omphalo-mesenteric canal with its vessels and the diverticulum of the cavity of the coelom; all these elements of the cord are covered by the amniotic epithelium.

The cavity of the amnion steadily increases and takes the place of the cavity of the chorion or external coelom, which

eventually disappears. The amnion, however, does not come into direct contact with the chorion, because there remains between the two membranes a thin film of mucous tissue (interconnective membrane or tissue) which is merely the residue of the *magma reticularis*, with which the cavity of the chorion was filled; at birth all these parts are removed with the after-birth.

IV. Pregnancy causes notable modifications in the whole of the genital apparatus of the woman, more especially in the uterus,

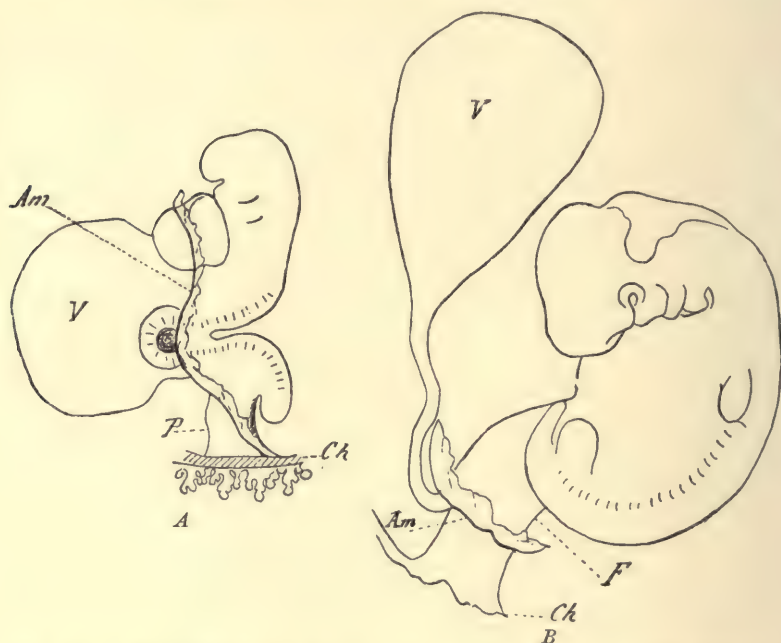


FIG. 98.—A, embryo measuring 2.15 mm., according to His; B, embryo measuring 9.8 mm., according to Minot. Am, line of attachment of the amnion; P, abdominal peduncle; F, umbilical cord; V, umbilical vesicle; Ch, chorion.

which has to receive the product of conception and support its progressive development during the ten lunar months which normally precede parturition. For this reason the wall of the uterus is not merely distended passively as the ovum increases in size, but also undergoes an active *eccentric hypertrophy* in all its component parts.

We have already spoken of the proliferation of the *uterine mucosa* by means of which the *decidua* and *placenta* are formed. No less important is the increase in volume of the *smooth muscular coats*, which, however, unlike the mucosa, is not effected by *new formation*, but by gradual *hypertrophy*, so that at the end of

pregnancy the fibres may attain a length of 500μ , that is, may become ten times longer than those of the virgin uterus, as is shown in Fig. 100.

The development of the blood-vessels proceeds at the same rate as that of the muscular system. In order to form an adequate idea of this it is only necessary to examine the figure of the pregnant uterus with the arteries and veins injected in a preparation by Hyrtl. In looking at it we are surprised at the turgescence, the dilatation, the numerical increase, the winding course and the multiple anastomoses of the veins which cross the muscular fibres in every direction. While the largest *uterine* and *internal spermatic* arteries are scarcely as thick as a crow

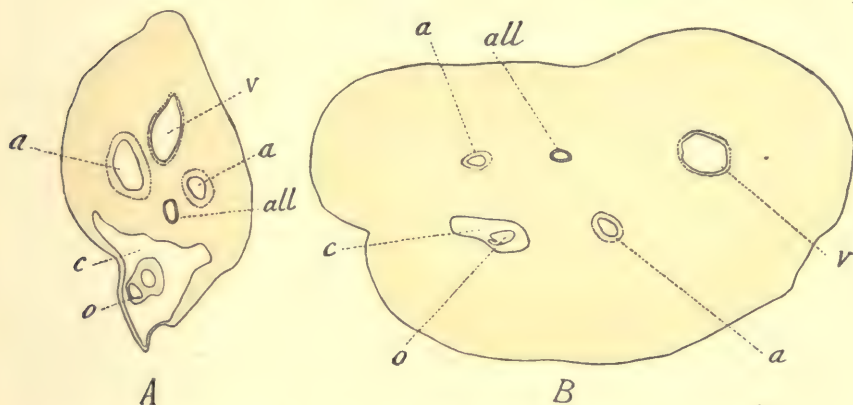


FIG. 99.—Transverse sections of the umbilical cord, according to Minot. *A*, embryo 21 mm. in length; *B*, foetus aged sixty-four to sixty-nine days. *aa*, umbilical arteries; *v*, umbilical vein; *all*, allantoid duct; *c*, coelom; *o*, peduncle of umbilical vesicle, accompanied by omphalo-mesenteric vessels.

quill, the largest venous trunks of the same name are as thick as the little finger (Fig. 101). The lymphatic vessels also increase notably in both number and size; they are invisible in Hyrtl's diagram, because they had not been injected. Gynaecologists have also described a hypertrophy and hyperplasia of the *nerves* and *ganglia*, which are related to the genital region and cover the wall of the uterus and its connections. On the other hand, the connective tissue surrounding the muscular fibres, vessels, and nerves shows during pregnancy a progressive tendency to softening and absorption of fluid, causing the component parts of the uterine wall to separate more easily and the organ to distend more readily, as is required by the increase in size of the ovum (Fig. 102).

The increase in thickness of the uterine wall reaches its maximum about the end of the third month; during the following

months till the end of pregnancy it gradually diminishes until it is reduced to 1-0.5 cm. in thickness.

The increase in the surface of the uterus and of its internal capacity is progressive from the beginning to the end of pregnancy ;

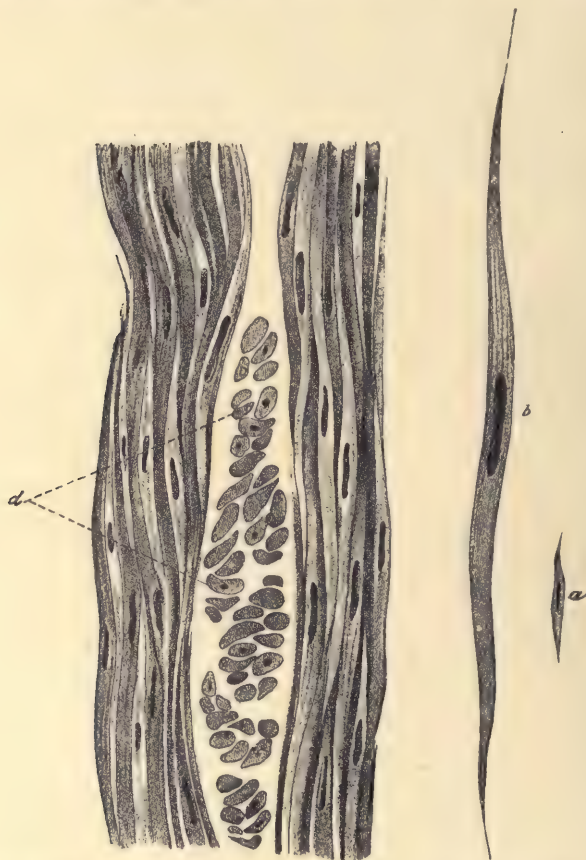


FIG. 100.—Smooth muscular fibres of the uterus. (Bumm.) *a*, fibre of non-gravid uterus ; *b*, fibre of gravid uterus at the tenth month ; *d*, transverse sections of fibres.

according to Krause its capacity becomes 519 times greater and the weight increases from about 50 to 1000 grms.

With the increase in size the uterus changes considerably in *shape* during pregnancy. The shape of the non-pregnant uterus is piriform ; in the first months of pregnancy it tends to become round, and the wall which corresponds to the placental insertion protrudes asymmetrically according to whether the placenta lies towards the right or left tube (Fig. 103). At the fourth month

the protuberance begins to become less noticeable owing to the growth of the other uterine cornu, and at the fifth to the sixth month the form of the uterus becomes ovoid, more rarely cylindrical, spherical, with one or two horns, cylindrical in a transverse



FIG. 101.—Gravid uterus with arteries and veins injected : from a corrosion preparation made by Hyrtl. From *Deskriptiven und topographischen Anatomie des Menschen*, by C. Heitzmann. 1, uterine artery ; 2, uterine vein ; 3, vaginal branch ; 4, spermatic vein ; 5, spermatic artery ; 6, vaginal plexus.

direction, according to the different congenital forms of the organ, the seat of attachment of the placenta, the size and position of the foetus.

The *position* of the uterus changes at the same time as its shape. As it ascends in the abdominal cavity it leans with its

anterior face against the ventral wall, almost always with the fundus inclined to the right.

The *cervix of the uterus* takes part in the hypertrophy of pregnancy and undergoes the same changes as the *body*; but the mucosa of the cervical canal is not transformed into decidua, but

preserves its epithelium intact. The mucous glands of the cervix secrete during gestation a tough, *transparent* mucus, which closes the uterine cavity like a stopper.

From the seventh month onwards the projection into the vagina of the cervix of the uterus, the so-called *tench mouth*, gradually disappears, so that if the fornix of the vagina be explored with the finger, the external orifice of the uterus is reached directly. It was formerly erroneously believed that as pregnancy advanced the cavity of the uterus increased in size at the expense of the *cervical portion*; numerous observations upon cases shortly before parturition have, however, clearly proved that the uterine neck and the cervical canal preserve their full length and undergo no change until the beginning of the contractions preceding parturition (Fig. 104). Obviously the so-called *destruction of the vestibule* is due to the fact that from the seventh month onwards the sinking of the head of the foetus brings greater pressure to bear on the lower segment of the uterus and distends it downwards together with the anterior vaginal fornix. The



FIG. 102.—Thin section of wall of gravid uterus, near full term. *a*, submucous layer; *b*, middle vascular layer; *c*, subserous layer. The muscular fasciculi are drawn aside in order to show better their course; in the middle layer numerous lacunae crossed by venous and arterial vessels are visible.

vagina and the *vestibule* become gradually softer during pregnancy owing to the venous hyperaemia, which may be recognised by the bluish colouring of the mucosa of the vagina and vulva, which finally becomes dark violet, because the venous vessels of these parts form, by their dilatation, a true vascular plexus.

During the state of gestation, the mammary glands attain

their full development, owing either to the action of the nervous system or the absorption of chemical stimuli (hormones).



FIG. 103.—Gravid uterus at three months, seen from behind. Drawing one third natural size. From a fresh preparation. (Bumm.) The ovum is planted in the left tubal angle; the oblique dotted line shows the boundary of the placental insertion; the transverse dotted line indicates the lower pole of the ovum; the lines starting above show the gradual transformation into a round shape during the following months.

The changes brought about in the organs surrounding the genital apparatus by the influence of the gravid uterus are of less importance from a physiological point of view. The *bladder*, the *ureters* and the *abdominal wall* feel the mechanical effects of

pressure when the uterus has attained a certain size. Obstruction to the return of venous blood from the lower limbs, which may cause varicose distension, is frequently observed. In the last month of gestation the increased size of the uterus exercises a mechanical influence also on the thorax, limiting the inspiratory movements of the diaphragm and widening its base in a transverse direction.

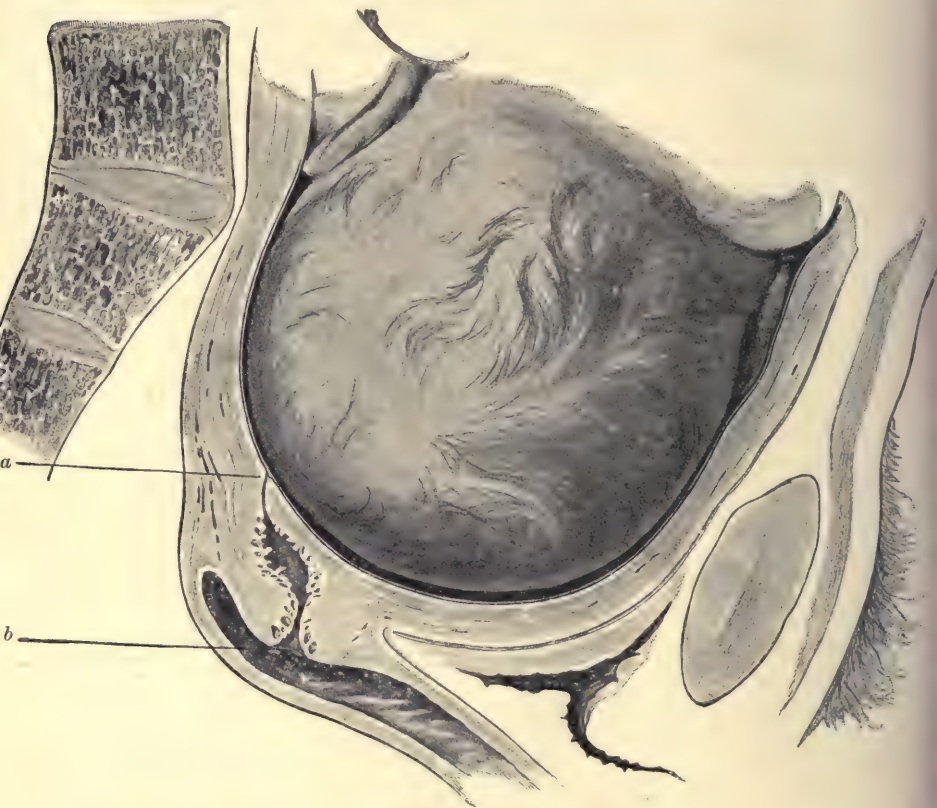


FIG. 104.—Tenth month: head in position in pelvis; anterior vaginal fornix introflexed and vestibule apparently destroyed. (Bumm.) *a*, internal uterine orifice; *b*, external uterine orifice.

It has been frequently erroneously supposed that *cardiac hypertrophy* was caused by pregnancy, this idea being due to the fact that percussion of the cardiac region at the end of gestation shows a *more extended area of absolute dullness*. This phenomenon is due to the higher level of the diaphragm, which forces the heart to assume a transverse position and incline more towards the anterior wall of the thorax (Gerhardt). For the same reason the apex of the heart is pushed about 2 mm. further

upwards and outwards. In many cases of pregnancy the resulting pressure on the heart produces *accidental cardiac murmurs*, which are no longer heard after parturition.

The raising of the *diaphragm* in pregnancy also causes a displacement of the *lungs*, by which the transverse diameter of the thoracic cavity becomes larger and the vertical diameter smaller (Dohrn). The diminished downward movement of the diaphragm and hence of the lungs also should bring about a considerable diminution of the pulmonary capacity during inspiration; this effect is, however, completely balanced by the increased activity of the muscles of the thorax (Vejas).

The progressive development of the uterus and foetus during pregnancy is naturally associated with a corresponding modification of the whole exchange of material in the mother. The woman gradually increases in weight, even when the quantity of food taken daily does not exceed the normal. Hence it follows that the gravid state increases the capacity for digesting and utilising food. From exact records of the increase in weight from the beginning to the end of pregnancy, Gassner concluded that during this period not only do the weights of the foetus and the genital apparatus increase, but also the bulk of the other organs and tissues.

The excretion of urine increases in a marked degree during pregnancy, especially towards the fifth month. It is a simple polyuria, accompanied by a diminution of the specific gravity of the urine. The production of urea, uric acid, sulphates, phosphates, and chlorides varies within physiological limits.

The total quantity of nitrogen discharged in the urine and the faeces during pregnancy does not exceed the normal; this signifies that a considerable part of the protein taken serves to augment the weight of the maternal and foetal organism.

A certain accumulation of fat, which is specially noticeable in the hepatic cells, is also found in pregnant women (Miotti). The glycogenic content of the hepatic cells also increases (Charin and Guillemont).

The *glycosuria* which is sometimes noticed is not more marked than that which is physiologically accounted for in normal man (Leduc). At the end of pregnancy, when the secretion of milk begins, *lactosuria* replaces *glycosuria* (Leduc, Brocard).

The urine very often contains albumen during the second half of pregnancy; it increases in quantity up to the time of parturition and then rapidly disappears. This phenomenon leads in many cases to a degenerative change in the renal parenchyma (von Leyden), which is usually attributed to various mechanical factors or to a form of auto-infection due to the change of metabolism, or even to micro-organisms.

During the second half of pregnancy *epithelium* from the

renal tubules is constantly observed in the urine, also *leucocytes*, and, more rarely, *erythrocytes* and *hyaline* and *granular cylinders*.

In consequence of the compression of the bladder and relaxation of the muscles of the vesical sphincter, frequent need of micturition and even involuntary discharge of urine, are common during pregnancy.

In pregnant women a series of changes may be noted for which a cause is not easy to find. Amongst such changes we may mention the abnormal *pigmentations* of the skin, not only in the external genital organs and the areola of the nipples, but also in the skin of the abdomen, face and limbs, to which the older obstetricians gave the name *chloasma uterinum*.

H. W. Freund has recently called attention to the so-called *dermographism* as an almost constant phenomenon in pregnancy. A blunt point or the nail of the finger drawn across the skin of the chest or abdomen will produce a red, raised line which may persist for some hours. After parturition this phenomenon, which is also sometimes noticed in hysterical patients, always disappears.

In about half the cases of pregnant women, from the third month onwards, excrescences or thickenings, termed by Ducrast and Rokitansky (1844) *puerperal osteophytes*, make their appearance on the internal surface of the bones of the cranium.

The teeth are abnormally friable and sensitive, a fact which is associated with a diminution in calcium fluoride (Terrier).

The increased bulk of the abdominal contents and the displacement forwards of the centre of gravity bring about a change in the carriage of the body, owing to the fact that in order to maintain the line of gravity posterior to the axis of rotation of the hips, the head and shoulders must be thrown somewhat back, thus increasing the lumbar curve. This condition is naturally more marked in short than in tall women, whose larger abdomen affords the foetus more space.

The organic changes as a whole which are caused by the gravid state tax the functional capacity of the organs to the utmost, causing in delicate or sickly women sufferings which may be of considerable intensity, and belong to the realm of pathology, since they do not occur in really normal women. Slight degrees of *hydraemia* and *leucocytosis*, irritability and depression, disturbances of the digestive functions, malaise, frequent vomiting, etc., are abnormal phenomena, which occur most frequently in young women and at the beginning of pregnancy.

V. Parturition is the greatest physiological effort of the female generative organs, as Sellheim justly remarks.

The mechanism by which the gravid uterus empties itself of its contents, when the foetus has attained the development requisite

to enable it to live detached from the maternal organism, is very similar to that by which the last portion of the intestine and the bladder, which are both contiguous to the genital canal, are emptied.

In these acts, as in parturition, the expulsive or ecboic work is effected by contractions of the smooth muscular fibres, forming the walls of the muscular cavities, aided by abdominal pressure, that is, by contractions of the muscles of the abdominal wall and the diaphragm. Notwithstanding the development attained by the body of the new individual in the higher animals and in man, its separation from the mother may be effected under physiological conditions without any artificial aid, and without injury to either mother or child, when the presentation is occipital, which is the case in about 95% of births.

The expulsive forces which determine parturition are specially due to peristaltic contractions of the smooth muscles of the uterus, assisted more or less by activity of the striated muscles in the production of abdominal pressure. The uterine contractions are usually accompanied by more or less painful sensations which are called *pains*, and are localised mainly in the sacral and lumbar regions, and later on extend to the region of the fundus of the uterus. The pains begin when the contractions assume a certain intensity, their severity increasing in proportion to the strength of the contractions.

The uterine contractions, like all those of smooth muscles, are independent of the will; their peristaltic character, that is their direction towards the outlet of the genital canal, cannot be perceived in the uterus of woman, owing to the rapidity with which they spread, but may be observed distinctly in the uterine cornua of animals, in which the contractions begin at the extreme end of the tube and spread like waves towards the external orifice of the uterus.

The contractions—and the pains accompanying them—have three stages, *increment*, *acme* and *decrement*. They last one minute on an average and are followed by a longer *pause* of muscular relaxation. The pauses between two successive pains last at first ten to fifteen minutes; later they become shorter, and towards the end of parturition succeed one another every minute or thirty seconds.

During the contractions there is an increase of intra-uterine pressure uniformly distributed both on the amniotic fluid and on the body of the foetus; this pressure Schatz has succeeded in measuring with a suitable manometer (Fig. 105).

We have as yet no clear or adequate knowledge of the *innervation* of the uterus.

The majority of the nerves of the uterus are of *sympathetic origin*, but cerebro-spinal fibres are not wanting. As may be

seen in Fig. 106, taken from a classic work by Frankenhäuser (1867), the *sympathetic nerves* running towards the uterus originate in the aortic plexus: they receive numerous fibres from the *solar ganglion*, the *renal ganglia*, the two *genital ganglia* and the *lumbar ganglia* of the sympathetic chain; at the level of the point of origin of the lower mesenteric artery they unite in a wide nervous plexus beset with ganglia called the *great uterine plexus*. Near the sacral promontory, this plexus divides into the two *hypogastric plexuses*, which surround the rectum, and make their way partly to the lateral margins of the uterus, partly to the *ganglia of the cervix uteri*; these form two wide plexuses situated at the upper part of the cervix of the uterus, and send branches to a great part of the uterus. The Fallopian tubes and the ovaries receive sympathetic fibres from the renal and genital ganglia, associated with the spermatic vessels.

The nerve-fibres of cerebro-spinal origin reach the uterus by different paths: by way of the *aortic plexus*, the *vagus*, the *phrenic*

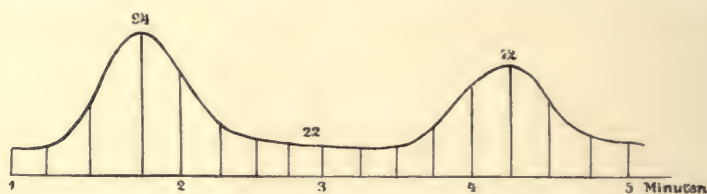


FIG. 105.—Normal curve of the uterine contractions during the period of dilatation; recorded by means of tocodynamometer. (Schatz, *Arch. für Gyn.* iii.)

and the *splanchnics*; from the *lumbar spinal cord* by means of the *rami communicantes*; finally, from the *sacral plexus* run many branches which join the *cervical ganglia* and go direct to the uterus.

Experiments made on animals to determine the function of these various nerves have not led to any concordant results. It is only certain that important *motor centres* for the uterus exist in the *medulla oblongata*, the lumbar portion of the *spinal cord* and the *great uterine plexus*. The *sensory nerves* appear to pass chiefly by way of the *sacral plexus*. It is extremely probable that the central elements of the ganglia of the great uterine plexus, the cervical ganglia and the more peripheral ganglia found in the walls of the uterus itself act as *reflex* or *automatic centres* for the regulation of the uterine contractions. It has, in fact, been proved that the activity of the uterus which develops during parturition may persist regularly in the bitch even after transverse section of the spinal cord at the level of the last dorsal vertebra (Goltz). It may therefore be concluded that the lumbar swelling of the spinal cord contains a regulating centre for the

uterine contractions, besides those for the bladder and rectum. It is also probable that motor nerves descending from the brain may act on the lumbar centre; this would be in harmony with

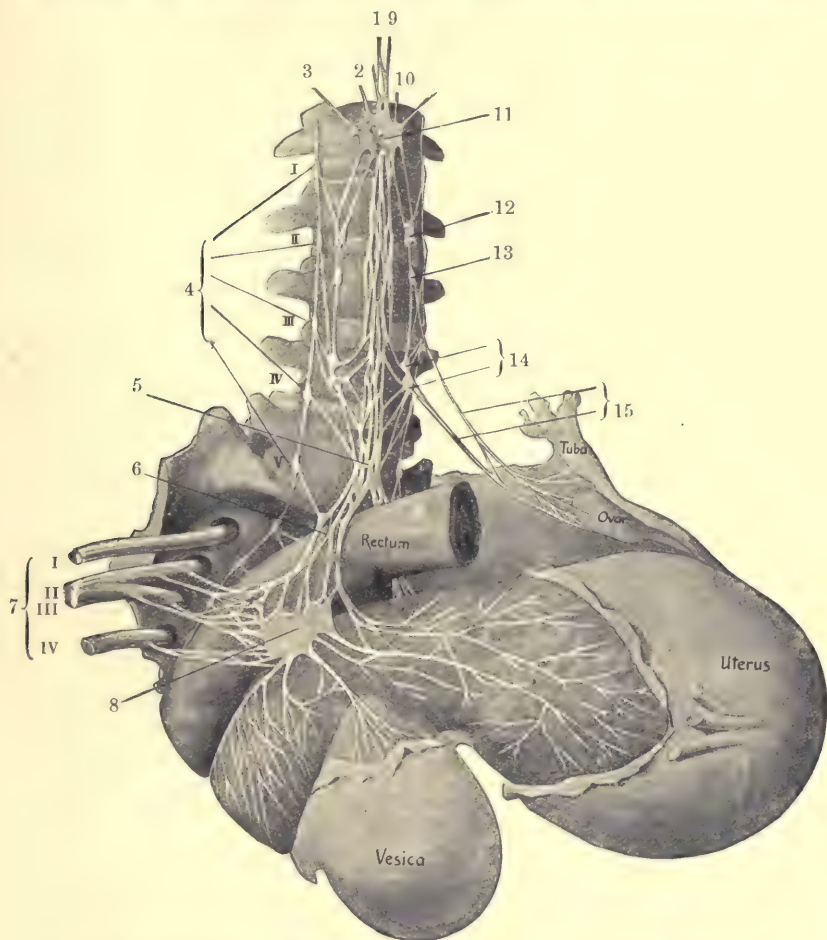


FIG. 106.—Nervous system of the female genital organs. (Frankenhäuser, *Die Nerven d. Gebärmutter*.) The upper part of the nerves has been added to Frankenhäuser's drawing. 1, aortic thoracic plexus; 2, phrenic nerve; 3, splanchnic nerve; 4, lumbar ganglia of the sympathetic; 5, great uterine plexus; 6, right hypogastric plexus; 7, sacral plexus; 8, right cervical ganglion; 9, vagus; 10, splanchnic nerve; 11, solar ganglion; 12, upper renal ganglion; 13, lower renal ganglion; 14, upper and lower genital ganglia; 15, spermatic plexus (ovarian nerves).

the fact, which has often been noticed, that psychic excitement, such as a fright or sudden and *violent* pain, may exercise such an influence on the frequency and intensity of the uterine contractions as to cause abortion or premature labour.

Since uterine innervation is not clearly understood, we are not as yet in a position to form an exact opinion as to the *causes which bring about labour* at the end of the fortieth week of pregnancy. It is certain that as the gravid uterus increases in size, the excitability of the uterine muscles is raised proportionately. During the last months and weeks of pregnancy the slight pains which mark a gradual transition from the painless contractions of gestation to the intense and painful contractions of labour occur more and more frequently. The hypertrophy of the muscular fibres and their steadily increasing mechanical compression probably cause the heightened nervous and muscular excitability. The progressive increase of pressure exerted by the foetal head on the lower part of the uterus, which is more liberally supplied with nerves, undoubtedly helps to maintain the contractile activity of the uterus so long as its contents have not been expelled. Another cause of parturition has been thought to be a progressive fatty degeneration of the decidua, which renders the relation between the ovum and the uterus less and less intimate, and at last makes the foetus an extraneous body as regards the mother. Finally, it cannot be denied that during the lying-in period the uterine contractions, which occur with increasing frequency, interfere more and more seriously with the gaseous exchange between the mother and the foetus; this gives rise to greater venosity of the placental blood, which in turn increases the excitability of the ganglia of the uterine walls, and causes the expulsive contractions and supreme pains which precede parturition.

It was formerly thought that the obliteration of the placental vessels was one of the internal conditions determining parturition; Chappentier (1889) observes, when writing on this subject, that the real cause of parturition must be sought in the vascular relations between the ovum and the uterus.

"The more the ovum is developed, the more will the intra-uterine pressure increase, causing an equivalent reaction of the uterine walls. The eccentric tension is counterbalanced by the concentric uterine reaction of the walls of the uterus. This contest, which is much more acute during the last period of pregnancy, gives rise to a secondary phenomenon, influenced by the increasingly intense uterine contractions: the closure of the vessels, which takes place at every contraction. At last the connection between the uterus and the placenta is so constantly interrupted that an intermediate zone is created in the thickness of the decidua between the ovum and the uterus, the *zone of rupture* of Langhans, Dohrn and Sinéty, in which the degenerate and fatty elements, and the partially or wholly obliterated vessels (Leopold) form a tissue devoid of resistance or vitality.

"From this moment, moreover, the ovum, having an inadequate

connection with the uterine walls, becomes an extraneous body, and every contraction of the uterus helps to expel it."

Spiegelberg, in order to explain why the various conditions we have enumerated bring about parturition exactly at the end of the fortieth week of gestation, advanced the hypothesis that the real cause of parturition must be the maturity of the foetus, which, during its development, utilises certain special chemical substances of an unknown nature, and ceases to utilise them as soon as it has reached maturity; these substances are then reabsorbed by the maternal blood, in which they act as hormones, capable of exciting all the nervous and muscular mechanisms which effect the expulsion of the foetus. We have mentioned that with the involuntary uterine contractions there are associated

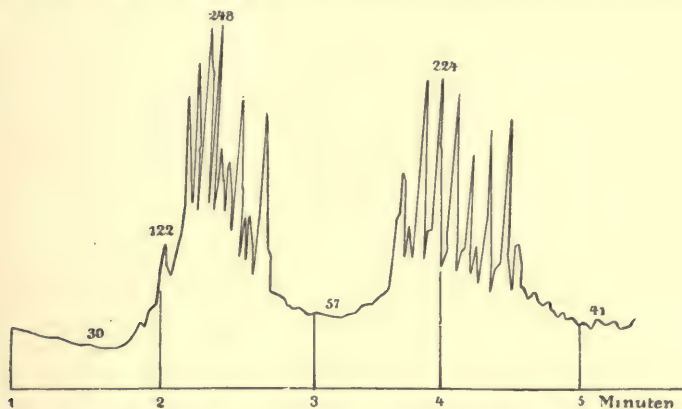


FIG. 107.—Curve of pressure and of contraction of uterus during the period of expulsion. (Schatz, *Arch. f. Gyn.* iii.) Synergic action of pressure and contraction. The apices of the curve coincide with the abdominal pressure.

in the last stage of parturition voluntary contractions of the abdominal muscles, which, by increasing the intra-abdominal pressure, support the uterine contractions and force the contents of the uterus towards the canal, which offers the least resistance to the total intra-uterine pressure.

Schatz has succeeded by his manometric method in recording the curves of the abdominal pressure associated with the uterine contractions during the period of expulsion (Fig. 107). We refer the reader to treatises on obstetrics for details concerning the passive dilatation which takes place in the cervix of the uterus, the vagina, vulva and perineum during the final act of parturition, the way in which natural parturition takes place according to the different presentations of the foetal head, and the artificial aids which are necessary for delivery in cases of difficult labour (*distocia*), which are usually caused by abnormal presentations of the head of the foetus.

We shall add a few words on the *ligature of the umbilical cord*, which must be attended to after the expulsion of the foetus, and the so-called *after-birth*, the placenta and the decidua.

If we examine the cord immediately after the expulsion of the child, we find that the arteries are still pulsating and the umbilical vein is turgid with blood. The vein becomes empty about five minutes later and the arteries cease to pulsate in about ten minutes. During this time, therefore, a considerable quantity of placental and umbilical blood reaches the infant, this blood being squeezed out from the uterine walls and the whole of the canal which retracts after delivery and presses the blood out of the placenta, as out of a sponge saturated with liquid. If the infant be placed in a balance immediately after expulsion, it will be found that this blood varies in quantity from 50 to 100 grms., that is to say, it is about a quarter or a third of the blood which circulates in the new-born infant. The child would lose this considerable amount of blood were the cord tied immediately after birth, as is done by many ignorant midwives, or those of the old school, instead of the necessary time being allowed for the umbilical vein to become empty.

After the expulsion of the child, the uterus contracts, causing the gradual detachment of the placenta and the decidua. In order to further this detachment, it is advisable, as recommended by Crede in 1854-61, to press on the uterus with the hand from without, so as to stimulate it and increase the pressure during contraction and thus bring about the expulsion of the after-birth or secundines.

This expulsion takes place from half to three-quarters of an hour after the birth of the child. The placenta and the membranes are expelled into the vagina and towards the vulva by the contraction of the uterus and the pressure of the hand of the obstetrician, so that a slight pull on the umbilical cord will complete the expulsion.

During the passage of the secundines it is advisable to twist into a strand the membranes which have not been expelled, so as to lessen the risk of their being torn and partially retained in the uterus (Fig. 108).

VI. After the expulsion of the child and the after-birth, the so-called period of *puerperium* begins, during which the generative apparatus of the woman returns to its pristine state, some slight but indelible internal and external marks of maternity remaining, however.

The puerperium lasts from six to eight weeks. The phenomena of *puerperal involution* take place mainly in the uterus. If we look at the genital canal of a woman who has recently been delivered (Fig. 109), we see that the uterus is represented by a voluminous flattened muscular mass, with walls 3-5 cms. thick, enclosing a small cavity filled with a clot of blood. At the point

of transition between the body and neck of the uterus at the level of the internal orifice, the thickness of the walls suddenly diminishes, and the whole cervical canal looks like a large sac falling into numerous folds. This cavity of the cervix is bounded above by a constriction called the *ring of contraction*; it is more open below and the lips of the mouth of the uterus descend into the vagina in the form of a fleshy intumescence. The vagina takes the form of a sac with many folds and walls sloping down towards the vulva. Owing to the great stretching of these walls, the uterus can easily be made, from above downwards, to sink



FIG. 108.—Twisting the membranes into a cord. (Bumm.)

in the pelvis by pressure of the hand on the abdomen, so that the "mouth of the uterus" may be seen at the vulvar orifice.

This state of things very soon begins to change gradually, as the tissues recover their tone and original consistence. The vulva contracts first, then the vagina, and in eight days they regain their normal tone. On the tenth day the tip of the finger can no longer penetrate the cervical canal. The external orifice only closes in the third week and assumes the appearance of a *transverse fissure*, a permanent mark of parturition.

The body of the uterus undergoes, during the puerperium, a marked process of involution owing to fatty degeneration of the muscular fibres which hypertrophied during pregnancy. This degeneration is the result of anaemia caused, during parturition

and the expulsion of the placenta, by the contractions of the uterine muscles, which continue to occur at intervals during the first three days of the puerperium, and are accompanied by painful



FIG. 109.—Genital canal of a woman recently delivered. (Bumm.) 1, internal orifice (ring of contraction) of uterus; 2, external orifice; 3, internal orifice (ring of contraction); 4, external orifice.

sensations, the *after-pains*, which are of special intensity in the pluripara. During these contractions the muscular fibres are forced together and compress the vessels passing between them. Owing to the diminished supply of blood, the protoplasm of the muscular fibres becomes turbid, little drops of fat are formed

which are afterwards reabsorbed, and the fibres gradually become smaller and in about four weeks reach their original dimensions (Fig. 110). Just as the hypertrophy of the muscular elements enlarges the bulk of the uterus during pregnancy, so the atrophy restores it to its pristine size. The atrophied muscular fibres do not, however, perish and give place to new ones; according to Sanger and other authorities, the nucleus and a portion of the protoplasm of each fibre lives on and undergoes hypertrophy again in subsequent pregnancies.

It is more difficult to determine histologically the changes which take place after parturition in the uterine arteries and veins, which during pregnancy—as we have already seen—are enormously developed, since they have to supply the blood which is necessary for the nutrition and respiration of the embryo, the foetus and the foetal adjuncts.

The haemorrhage which follows the expulsion of the foetus and its adjuncts is normally slight, owing to the early and energetic contraction of all the muscles of the uterus, including the circular fibres, which are well developed in the small arteries. This *immediate* haemostasis becomes *permanent* and *definitive*, because the venous vessels are blocked by the formation of thrombi, which later become organised, and the arterial vessels—according to Balin (1880)—are reduced in diameter and obliterated by the development of

connective tissue in the intima, with total or partial fatty degeneration of the muscular portion of the tunica media. Reiss (1892) found the vessels of the puerperal uterus of woman for the most part occluded and considerably reduced in diameter. Braers (1895) accounted for this complete or partial obliteration of the uterine vessels by a proliferation of the intima.

More precise histological researches into the changes undergone by the uterine vessels after parturition, compared with those which take place during pregnancy, have so far only been carried out on animals, white mice, and guinea pigs. The first works on the

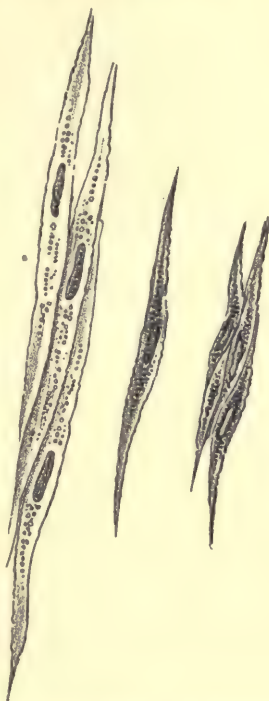


FIG. 110.—Smooth muscular fibres of the uterus in process of fatty degeneration. (Bumm.) Sixth, tenth, and eighteenth day of puerperium.

subject, published by Silvansky (1897), D'Erchia (1898), and Raineri (1903), were followed by a more complete account by Stolper and Hermann (1904), who endeavoured to explain the origin of the proliferation of the intima which causes the puerperal involution of the uterine arteries in guinea-pigs.

Almost at the same time Piana (1903), when treating of the same subject, enunciated views diametrically opposed to those of the above-named authors. According to him, the enormous enlargement of the uterine arteries in the guinea-pig during pregnancy is not due to dilatation of the lumen of the vessel, but to cellular proliferation of all the strata of its walls, more especially of the intima and the endothelium, from which large lymphoid cells are developed, some by karyokinesis, having numerous smaller elements with nuclei staining deeply which gradually become detached and mingle with the circulating blood. On the ground of these discoveries he set up the hypothesis that the uterine arteries of the guinea-pig assume during pregnancy a *haemopoietic function*, which gradually comes to an end during the puerperium in proportion as the process of involution in the vessels advances, and the uterus returns to its ordinary pre-gravid state.

La Torre (1907) repeated Piana's investigations with the greatest care, verified the results, but did not consider Piana's theories proved by them. Thus with reference to this interesting subject we have not a few facts of uncertain significance which have still to be explained by research work differing in method or made on other animals.

Lactation is of considerable assistance to the regular puerperal involution of the uterus, perhaps because the mammary gland utilises the organic materials formed by the retrogressive process of the genital apparatus.

The lacerations and contusions of the perineum, the vagina and the cervix, caused by the passage of the infant through the relatively narrow channel, heal during the first few days of the puerperium. *The large wound in the endometrium*, which is due to the detachment of the after-birth, and on account of which the condition of the recently confined woman has frequently been compared to that of a patient who has undergone an amputation, is completely healed in about three weeks by a special process of repair. We mentioned that the superficial stratum of the decidua is detached and expelled during the after-pains. For the *restitutio ad integrum* of the large wound resulting from this, a real regeneration of the uterine mucosa and of its epithelial covering must take place.

During the first period of the puerperium, the residua of the old mucosa are invaded by a great number of leucocytes, which form a barrier of granulation tissue towards the surface. The external strata of the decidua become necrosed, are eliminated

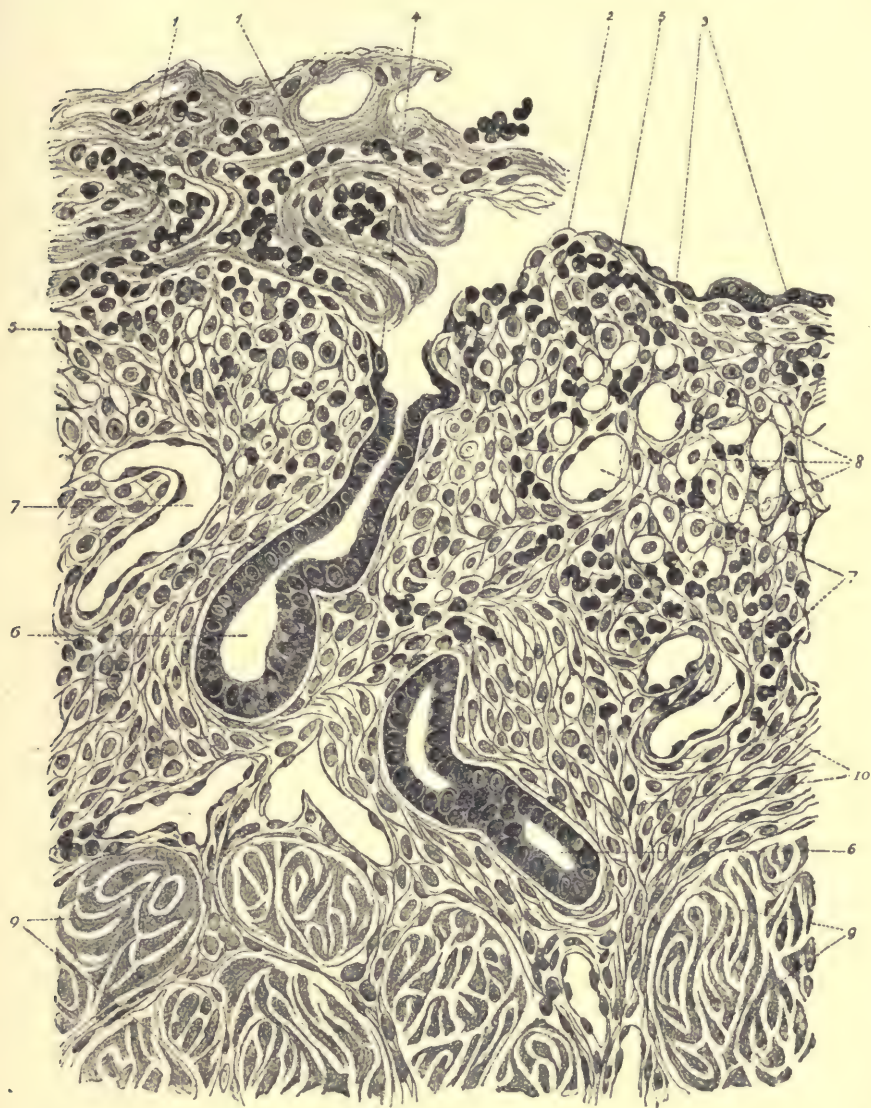


FIG. 111.—Section of the uterine mucosa in course of regeneration at the sixth day of the puerperium. (Bumm.) 1, necrosed superficial stratum of the decidua in course of elimination showing leucocytic infiltration; 2, denuded surface of the decidua; 3, epithelial covering being formed afresh, semi-fluid protoplasm, amitotic reproduction of the nuclei; 4, epithelium growing out from a gland; 5, wall of granulation tissue forming a line of demarcation of the necrosed superficial stratum; 6, blind end of gland of decidua; 7, capillary vessels; 8, decidual cells in course of degeneration, surrounded by a network of connective fibres; 9, muscularis; 10, deepest stratum of decidua with spindle cells.

through the canal and replaced by connective tissue. At the same time there occurs in the blind ends of the uterine glands a rapid proliferation of epithelial cells which protrude from the glandular orifices in the form of a semi-fluid mass, rich in nuclei, and regenerate the epithelial covering of the mucosa (Fig. 111).

The regeneration of the mucosa and of the uterine epithelium may be considered complete at the end of the third week. During this period the *exfoliation* of the surface of the endometrium is accompanied by the *puerperal flux* or *discharge of the lochia*. This during the first days consists of blood coming from the vessels of the decidua serotina (*sanguineous lochia*). On the third day the lochia become paler (*serous lochia*), and are composed of serum, erythrocytes, leucocytes, fragments of decidua and epithelium. After the first week the lochia become greyish white (*white* or *creamy lochia*) and consist of mucus from the cervical canal mixed with numerous leucocytes. Finally during the third week the lochia gradually diminish and are reduced to the expulsion of a little transparent mucus.

The lochia coming from the uterus are normally sterile, inodorous, or with a slight smell from the aseptic secretions; but during their passage through the vaginal canal and vulva they become mixed with numerous microbes which are found there in considerable numbers, as was first pointed out by Doderlein, and are represented by cocci and bacilli of various kinds, and this gives the *vaginal lochia* an acrid odour of decomposition. These microbes, however, if they do not ascend to the endometrium, are not absorbed, owing to the defence made against them by the pavement epithelium of the vagina; hence they do not give rise to general infective phenomena or cause any feverish rise of temperature.

During this progressive involution of the genital apparatus, the mammary glands enter upon full physiological activity. As we saw in Vol. II. Chap. IX., the state of pregnancy causes vigorous development of the alveoli of the glands. We may add here that the development of the mammae is shown in tumefaction and hyperaemia of the organ, shown externally by a cutaneous network of dilated bluish veins, and also by the lancinating pains noticed by pregnant women. As early as the second month of gestation it is possible to squeeze out of the nipple some drops of *colostrum*, which increases in quantity as pregnancy advances.

In the colostrum the microscope shows small drops of fat unequal in size, mixed with exfoliated epithelium from the alveoli of the glands and ducts, and with the so-called *corpuscles of the colostrum* discovered by Donn ; these corpuscles are merely leucocytes which have migrated into the alveoli of the glands and act as phagocytes, enveloping the more minute drops of fat (Fig. 112).

The secretion of the true milk begins on the second or

third day after parturition, and is often accompanied by sudden turgescence of the glandular mass, increased sensitiveness of the nipple, painful irritation of the axillary glands and an increase

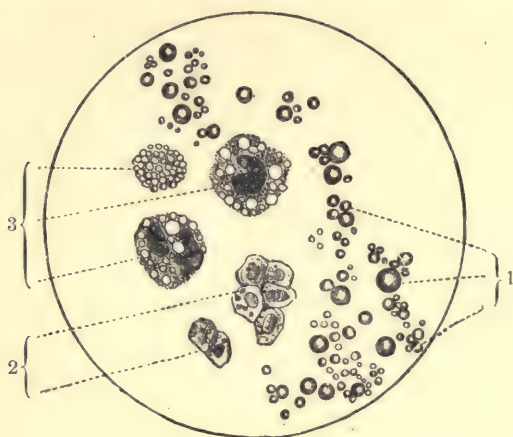


FIG. 112.—Structural elements of the colostrum. (Bumm.) 1, drops of fat of various sizes; 2, epithelia of mammary ducts; 3, colostrum corpuscles (leucocytes which have enveloped fatty globules), some of which still possess a nucleus.

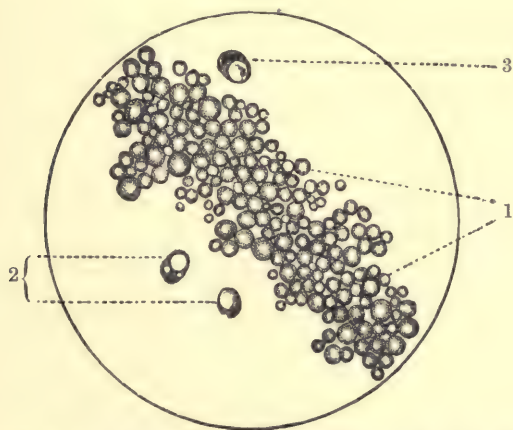


FIG. 113.—Structural elements of milk. (Bumm.) 1, drops of fat (milk globules); 2, milk globules with remains of protoplasm of the glandular epithelium; 3, milk globules with such protoplasmic remains containing nuclei, i.e. the whole glandular cell.

in the temperature of the axilla of 0.5° – 1.0° C. (*Milk fever*). In a few days and in proportion as the glands are emptied these signs of congestion become less marked and disappear.

Under the microscope the true milk appears to be composed of a clear plasma, in which float many little droplets of fat, some

of them showing on their surface the residue of the epithelial protoplasm from which they originate (Fig. 113). In the chapter already mentioned we have dealt at sufficient length with the histological and chemical processes by which the milk is formed, and with the influence of the nervous system on the secretion. The general health of the mother suffers very little from the profound changes which have taken place in the genital apparatus. The feeling of tiredness, a natural consequence of the labour of child-birth, disappears during the first few days, if the process of involution of the uterus progresses physiologically. In about a third of the cases of lying-in women, the puerperium is ushered in by a *shivering fit* which follows the after-pains and lasts from five to ten minutes. This shivering is of no morbid importance; it is due partly to the cooling of the woman during the confinement, partly to the withdrawal of the source of heat represented by the foetus and its adjuncts, partly to the muscular fatigue undergone during parturition and to the re-absorption into the circulation of the catabolic products of the metabolism in the muscles. During the first twelve hours after parturition there is a slight rise of temperature (37.8° - 37.9°), but the temperature becomes normal again on the second day (36.5° in the morning, and 37.5° in the evening). The *pulse* of the normal woman during the puerperium is remarkable for its slowness (60-50-40 beats a minute). This phenomenon (which is termed *puerperal bradycardia*) is a very favourable prognostic sign, and usually disappears after the first week. The frequency of the *respiratory movements* is also diminished during this period. During the first week after child-birth the *quantity of urine* increases; it sometimes contains *lactose* and traces of *peptone*. The *secretion of sweat* also increases, causing a sensation of thirst. Owing to the relaxation of the abdominal walls and the effect of bland food, the expulsive activity of the intestines is sluggish. After the first week the weight of the body shows a falling-off, about 3-4 kgs., which is naturally accounted for by the increased discharge of urine, sweat, lochia and milk. This loss of weight is soon made up; indeed during lactation the desire for food and the digestive capacity increase and a tendency to put on fat is usually noticed.

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CHAPTER VII

THE STAGES OF LIFE AND DEATH¹

SUMMARY.—1. The functions of embryonic and foetal life. *Omphalo-mesenteric* circulation and *cardio-placental* circulation. 2. The first phases of extra-uterine life; the establishment of the *cardio-pulmonary* circulation; the physiology of the *new-born* child. 3. The theory of *growth*; the *anaplastic period*; criteria for its estimation deduced from the length and weight of the body and the development of the skeleton. 4. The three periods of *childhood*; the rhythmical variations in growth from early infancy to puberty. 5. *Youth*; the three periods of *maturity* and *virility*; the *critical age* in woman and man. 6. The ancient and modern theories of *senility*. 7. The bodily basis and the phenomena of physiological and pathological senility of the whole organism and of single organs. 8. Modifications of the intelligence, affections, character, and psychical personality in the aged. 9. My theory of *death*; the death of the tissues and the death of the whole organism; Bichat's tripod of life and death; the *primum moriens* and the *ultimum moriens*. 10. The psychical phenomena of the period preceding death; *euthanasia* and the *fear of death*. Bibliography.

IF we consider the normal course of human life from the first development of the product of conception in the mother's womb, the life of the new-born infant, the child, the youth, the mature man, down to extreme old age and death, we may distinguish, as does Preyer, *three great periods*: the first, *the period of increasing development and energy*, is *anaplastic*; the second is the *state of maturity and dynamic equilibrium*; the third, *the period of retrogressive involution and decreasing energy*, is *cataplastic*. Popular wisdom has compared the succession of the periods of life with that of the seasons. They undoubtedly rest upon a real anatomical and physiological foundation. Man, as he passes through the different stages, changes proportionally in stature, in the development of his tissues and organs, in the significance and activity of his functions, and in the character and quantity of his products of metabolism.

¹ I have much pleasure in informing my readers that I am greatly indebted for the ancient and modern literature bearing on the interesting subjects discussed in this chapter to the assistance of my young and gifted friend Dr. Guglielmo Bilancioni, who placed at my disposal all the material collected by him at the cost of much labour and trouble. I have drawn on it more particularly for what seemed to me important from the point of view of my book, passing over what had a purely historical interest.

Of all the morphological and functional changes which occur during the various natural periods in the course of life, the most important is undoubtedly that by which man acquires the power of reproduction described in Chapters IV. and V. It exercises in both sexes the greatest influence on every part of the organism, as well as on the generative system. Just as *birth* draws a line of demarcation between *intra-uterine* and *extra-uterine* life, so *puberty* separates *infancy*, *childhood*, and *adolescence* from *youth* and *virility* or *maturity*, and the cessation, absolute or relative, of the generative capacity, which in woman is clearly marked by the *menopause*, separates maturity from *green old age* and from *advanced age* or *decrepitude* which eventually ends in *death*.

The greatest philosophers and physicians have treated of the ages of man in their works; we may mention amongst others Aristotle in his *De juventute et senectute*; Bacon in his *Historia vitæ et mortis* (1623), in which he follows closely the course of human existence in its phenomena of growth and decay; Ettmüller in his dissertation *De vitæ periodis* (1725); G. A. Testa, the physician of Ferrara, in his classic treatise entitled *Elementi di dinamica animale* (1783); Esparron, the pupil of Bichat, in his *Essai sur les âges de l'homme* (1803). In this chapter we shall sum up as briefly as possible the most interesting teachings of modern science on the physiology of the stages of life and death.

I. For an account of the first phases of the development of the *germ*, which are known as *embryonic life* and last until the third month from conception, we refer the reader to the preceding chapter, and to special works on embryology for everything concerning the genesis of the organs and the development of the *foetus*, as the uterine product is termed from the third month of gestation to birth. We shall confine ourselves to describing the chief functions of intra-uterine life, which may be summed up as consisting essentially of *foetal circulation*, *respiration*, and *nutrition*, knowledge of which is of the greatest theoretical and practical value.

So long as the blood-vessels are not developed in the embryo, all its vegetative functions are carried out by means of currents of plasma which originate in the secretions of the uterine mucosa, pass into the blastodermic vesicle, and are used for the development of the tissues. After the formation of the blood-vessels of the embryo, two forms of circulation may be distinguished, each of which is adapted to the mode of life of the embryo and the foetus, the way in which it breathes and is nourished, during two different periods of development. The *first circulation* is carried on between the heart of the embryo and its blood-vessels, which are still few in number and are united with the vascular net-

work extending over the surface of the umbilical vesicle (*omphalo-mesenteric* circulation (Fig. 114)); the *second* circulation occurs



FIG. 114.—Omphalo-mesenteric circulation. 1, omphalo-mesenteric artery; 2, embryo; 3, omphalo-mesenteric vein; 4, umbilical vesicle.

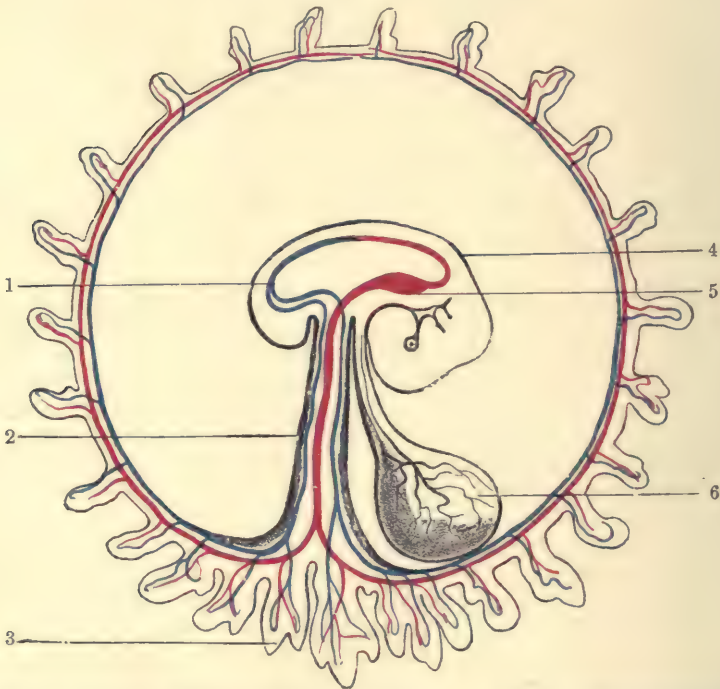


FIG. 115.—Allantoic or chorionic circulation. (Schematic.) 1, aorta; 2, allantois (abdominal peduncle); 3, chorionic villi; 4, embryo; 5, heart; 6, umbilical vesicle with impervious vessels.

between the heart of the foetus and its vessels, which have almost acquired their final form, and extends to the great vascular network which supplies the placenta (*cardio-placental* circulation or *allantoic vesicular* circulation (Fig. 115)).

The *omphalo-mesenteric circulation* is that which takes place during the first phase of development of the cardio-vascular system, when the heart is represented by a simple pulsating tube which curves in the shape of an S. The arterial extremity of this tube divides into two branches which go to form the *primitive aortae* which run parallel as far as the caudal end of the embryo. From each of these arteries start five or six collateral branches, two of which, the *omphalo-mesenteric arteries*, pass out from the embryo through the ventral opening and ramify in the upper half of the umbilical vesicle. This arterial network is continued in a venous network with large meshes ending in the *vena* or *sinus terminalis*, which represents the extreme limit of the vascular area. From the extremity of the *sinus venosus* pass the two *omphalo-mesenteric veins*, which run together to the venous end of the cardiac tube. In this way the *omphalo-mesenteric circulation* is established. The blood, forced from the arterial extremity of the cardiac tube, passes through the aortic arches, the thoracic aorta, the two *omphalo-mesenteric arteries*, the arterial network which traverses the upper half of the umbilical vesicle, and the venous network to the *sinus venosus*, and returns to the heart by way of the *omphalo-mesenteric veins*.

The importance and duration of this *first circulation* is in mutual relation with the importance and persistence of the umbilical vesicle. In the egg of the fowl and oviparous animals in general it is of great importance and constitutes the nutritive and respiratory apparatus of the embryo during the whole duration of its development. But in the mammals and in man the umbilical vesicle is so slightly developed, persists for such a short time, and contains so little food-stuff, that it can never serve any function indispensable for the development and life of the product of conception.

The nutrition of the human embryo is supplied much less at the expense of the yolk, which is extremely scanty, than of the nutritive fluids surrounding the ovum in the interior of the womb. These nutritive juices, absorbed by the layers of the blastoderm, penetrate also into the umbilical vesicle, which becomes dilated and enlarged, and from this its vessels draw the materials, probably modified and elaborated, which, through the circulation, provide for the nutrition and development of the embryo. Although the umbilical vesicle very soon atrophies, in proportion to the development of the vascular apparatus of the placenta, yet its two chief vessels persist even after the placenta is well formed. One of the two *omphalo-mesenteric arteries* becomes a branch of the mesenteric artery, and one of the *omphalo-mesenteric veins* becomes a branch of the mesenteric vein and a tributary of the portal vein.

In order to form a clear conception of the *second circulation*, which is set up after the development of the allantois and the complete formation of the placenta, and is therefore called *cardio-placental circulation*, we must first consider the anatomical

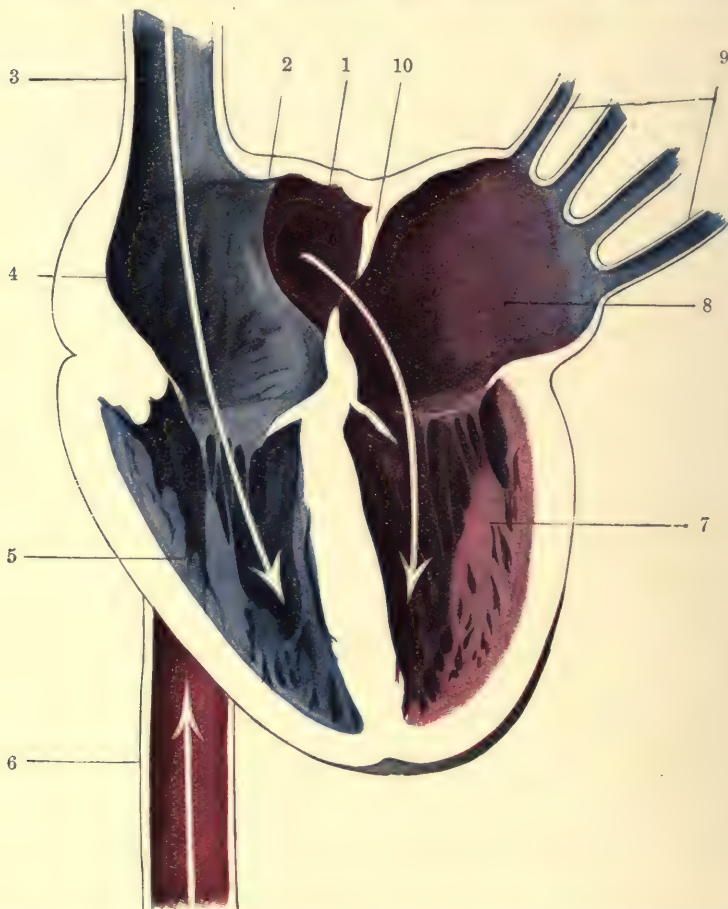


FIG. 116.—Filling of the foetal heart in diastole. Enlarged section of the heart of a new-born child. (The white arrows show the direction in which the blood flows.) 1, opening of the inferior vena cava in the right auricle; 2, Eustachian valve; 3, superior vena cava; 4, right auricle; 5, right ventricle; 6, inferior vena cava; 7, left ventricle; 8, left auricle; 9, pulmonary veins; 10, limbus of the foramen ovale.

peculiarities of the cardio-vascular system of the foetus. Whereas in the adult the right heart is entirely separated from the left by the inter-auricular and the inter-ventricular septum, in the foetus the right auricle communicates with the left by means of the foramen, known to Galen but called the *foramen ovale Botalli*,

which allows the blood returning by the venae cavae to pass from the right to the left side of the heart (Fig. 116). Whereas in the adult there exists no communication between the system of pulmonary vessels or *little circulation* and the system of aortic vessels or *great circulation*, in the foetus the system of pulmonary vessels communicates freely with the aortic system by means of a canal, also known to Galen, called the *ductus arteriosus Botalli*. It springs from the pulmonary artery before its division into two pulmonary branches, and opens into the aorta beyond the origin of the innominate, the common carotid, and the left sub-clavian (Fig. 117). In addition, the foetal placenta adherent to the uterine mucosa is connected by arterial and venous vessels with the vascular system of the foetus. The two *umbilical arteries* arise in the *hypogastrics* or *internal iliacs*, pass through the cord, and branching up, form the capillaries of the placenta, from which arises the *umbilical vein*; this vein passes through the cord in the opposite direction (Fig. 118) and divides into two branches directly it enters the abdomen of the foetus, one of these branches, the *ductus venosus Arantii*, running into the inferior vena cava, the other distributing itself in the liver (Fig. 119). After these anatomical preliminaries we can follow the course of the foetal blood stream and note the changes undergone by the blood during its passage from the foetus to the placenta and thence to the foetus.

The blood brought to the placenta by the two umbilical arteries is distinctly venous, that is, it is poor in oxygen and rich in carbon dioxide and products formed by the respiration and the nutritive exchanges of the foetal tissues. When it reaches the placental capillaries, it enters into relation with the maternal arterial blood circulating in the uterus so that a double change in opposite directions takes place: *the maternal arterial blood becomes venous and the placental venous blood becomes arterial*, after discharging carbon dioxide and waste products, and absorbing oxygen and nutritive materials. The umbilical vein thus brings back to the foetus blood which is *distinctly arterial*. Before, however, reaching the heart of the foetus it mingles with the venous blood returning from the foetal extremities to the heart by the inferior vena cava, so that it becomes *less arterial*. Only part of this arterial blood goes to the liver, where it mixes with the venous blood of the portal vein. At the point where the hepatic veins coming from the liver open into the inferior vena cava the arterial blood which the cava contains undergoes a second diminution of its arterial character, so that the blood which reaches the heart of the foetus is *less arterial than that contained in the umbilical vein*.

When this blood reaches the right auricle, it mingles with the venous blood flowing from the upper limbs and the head

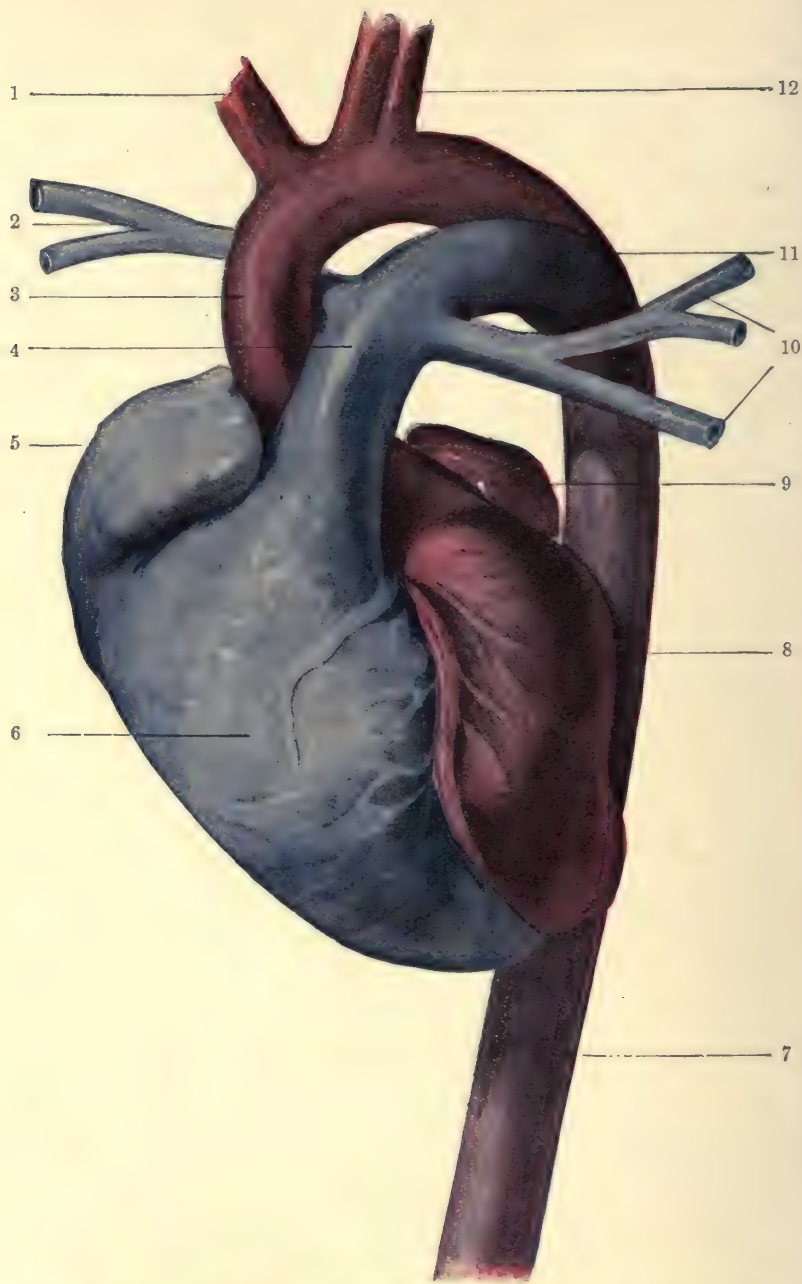


FIG. 117.—Emptying of the foetal heart in systole. Enlarged figure of the heart of a new-born child. 1, innominate artery; 2, right pulmonary artery; 3, ascending aorta; 4, pulmonary artery; 5, right auricle; 6, right ventricle; 7, descending aorta; 8, left ventricle; 9, left auricle; 10, left pulmonary artery; 11, ductus arteriosus Botalli 12, carotid and left subclavian arteries.

through the superior vena cava; this mixture is however really

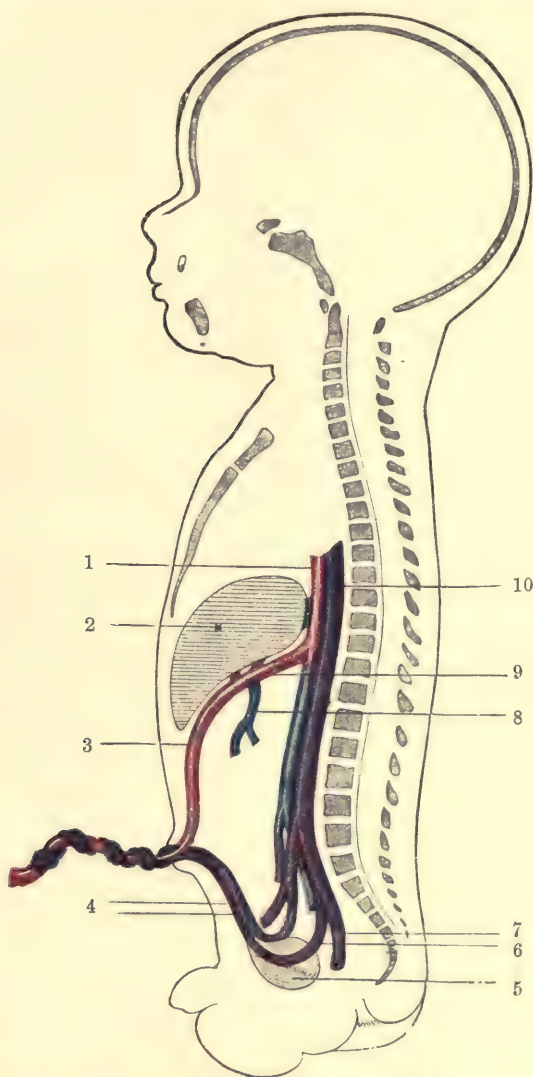


FIG. 118.—Course of the umbilical vessels in the foetal body. (Fr. Meckel.) Median section of the body of the fetus. 1, inferior vena cava; 2, liver; 3, umbilical vein; 4, umbilical arteries; 5, urinary vesicle; 6, hypogastric artery; 7, external iliac artery; 8, portal vein; 9, ductus venosus Arantii; 10, descending aorta.

only partial, since by means of an anatomical arrangement—the so-called Eustachian valve (Fig. 116) with which the entrance

to the inferior vena cava is provided—the greater part of the arterial blood brought by the inferior vena cava passes from the right to the left auricle through the *foramen ovale*, and the greater part of the venous blood brought by the superior vena cava flows from the right auricle into the right ventricle. When,

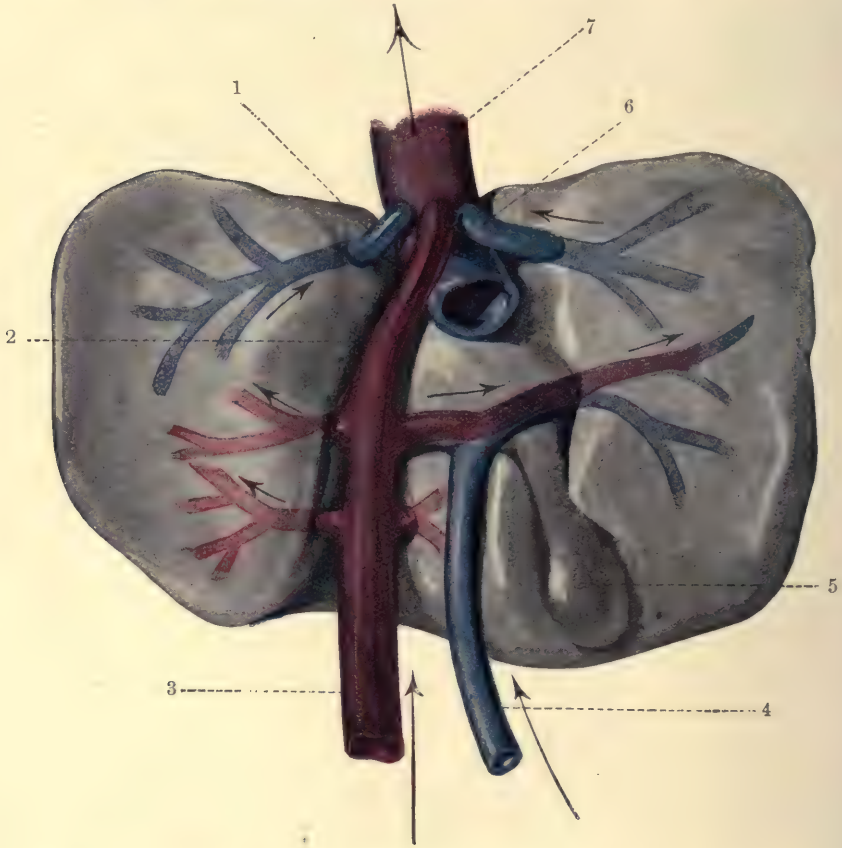


FIG. 119.—Foetal liver with its vessels. From Kollmann's *Embryology*. (Seen from the lower posterior surface.) 1, hepatic vein; 2, ductus venosus Arantii; 3, umbilical vein; 4, portal vein; 5, gall bladder; 6, hepatic vein; 7, inferior vena cava.

therefore, the heart is emptied during systole, the right ventricle forces through the pulmonary artery blood which is *almost entirely venous*, and the left ventricle forces through the aorta blood — which is *chiefly arterial*.

Only a small part of the blood conveyed by the pulmonary artery passes through the four pulmonary veins into the left

auricle; the greater part passes through the ductus arteriosus and mingles with the blood of the descending aorta. Thus much arterial blood coming from the inferior vena cava enters the left auricle, but very little venous blood from the pulmonary veins. This mixed blood, which is mainly arterial, passes from the left auricle into the ventricle below, flowing thence through the aorta partly to the upper limbs and head, partly to the lower limbs. The blood which goes to the upper limbs is more arterial than that which flows into the lower parts, because the latter contains a large admixture of the venous blood coming from the pulmonary artery and passing into the descending aorta through the ductus arteriosus Botalli. It is probably due to this fact that the head and upper limbs of the foetus develop more rapidly than the pelvis and lower limbs.

In conclusion we may say that, contrasted with the adult, in whom the arterial blood passing through the left heart is absolutely separated from the venous blood passing into the right heart, in the foetus, in most parts of the circulation, the vessels conveying arterial blood laden with oxygen and histogenic materials are in communication with those conveying venous blood deficient in oxygen and nutritive substances, so that a mixture of the two kinds of blood takes place. This difference in the circulatory system is in perfect harmony with the needs of the foetus, which differ essentially from those of the adult. The adult must be able to move and work, therefore his tissues, and more especially his muscles, consume a large quantity of oxygen, which is indispensable for the development of heat and force. The chief requirements of the foetus, on the contrary, are growth and development, for it has but little need of heat and movement. During intra-uterine life the respiratory muscles do not work; the active movements of the foetus are accomplished with a minimum expenditure of energy, for in the maternal uterus it is immersed in the amniotic fluid, and has not therefore even to support the weight of its own body. Moreover, the foetus requires but little oxygen for the production of heat, especially during the first months, for loss of heat is prevented by the mother's body. The need of oxygen, however, increases gradually in proportion to the growth of the foetus, and provision is made for this need by the gradual development of the placental vessels, and the proportionate increase in the intensity of the exchange of the respiratory gases between the uterine and placental blood. Although the blood of the foetus contains as a rule less oxygen than that of the mother, because it does not need to consume so much, still its temperature is always somewhat higher than that of the maternal blood (on an average 0.5° C.); this is due to the very limited loss of heat from the foetus and to its own production of heat.

It is certain that the exchange of material and energy in the foetus is carried out under much more favourable conditions than those in extra-uterine life. All the oxygen and histogenic materials it needs are supplied to it by the blood brought by the umbilical vein from the placenta, which represents, as Mayow has well said, its *respiratory and digestive apparatus*.

Zweifel (1876) was the first to observe by opening the abdomen of a pregnant rabbit, immersed in a bath of physiological saline at 38°, that if the foetus be carefully removed without disturbing the umbilical vessels, the umbilical vein shows the bright colour of arterial blood, whilst the blood of the umbilical arteries is dark. Thus the foetal blood on its way through the superficial capillary network of the villi of the chorion takes up oxygen and gives off carbon dioxide by a process similar to that occurring in the lungs, the foetal being separated from the maternal blood circulating in the intervillous spaces only by the thin walls of the vessels and by the epithelium of the villi. The transudation of histogenic substances from the lacunae of the villi to the vessels of the placenta is very active, corresponding to the rapidity of foetal development.

We have numerous experimental proofs that diffusible substances pass from the mother to the foetus. If sugar be injected into the maternal vessels, it is found in large quantities in the foetal tissues; if atropine be injected into the mother, midriasis is observed in the foetus (Thomas and Gillette); the foetus can be killed by giving the mother strychnine, or even curare, which has a weak degree of diffusibility. The following substances given to the mother during the last stage of pregnancy are found in the body and first urine of the new-born child: phosphorus (J. Clouet); salicylate of soda (Benicke, H. Fehling); bromides, ferrocyanides, potassium chloride (Porak); copper acetate (Philippeaux); iodide of potassium, tincture of iodine (Gusserow, Krukenburg, Heidlen); and other medicinal substances. Certain pathogenic germs also pass from the maternal blood to that of the foetus—a fact of great importance with reference to the genesis of hereditary diseases.

The process by which anabolic products pass from the mother to the foetus and catabolic products from the foetus to the mother is however certainly not one of simple diffusion. As a matter of fact, the specific gravity of the foetal blood is greater than that of the maternal. This difference proves that the epithelial cells of the decidua and those of the placental villi exercise a function similar to that of the intestinal epithelium. The protein substances of the maternal blood probably undergo some modification during their transmission to the foetus. We do not know whether the fats of the maternal blood, which Fehling thinks increase as pregnancy advances, are supplied to

the foetus as such. The presence of glycogen in the placenta, discovered by Cl. Bernard, demonstrates that it possesses a glycogenic function similar to that of the liver in the adult.

In addition to the respiration and nutrition of the foetus, the placenta serves also for the elimination of its waste products, thus performing a function analogous to that of the kidneys. The blood flowing from the venous sinuses of the decidua serotina is indeed rich in broken-down substances from the tissues.

The active exchange of materials between the mother and the foetus results in a rapid growth of the tissues which is not equalled at any stage of extra-uterine life. Many numerical data of the increase in volume and weight of the human foetus have been collected by Autenrieth, Chossier, Hecker, Hemming, His, Fehling, Toldt, Kölliker, and others. Owing, however, to individual bodily differences and to the difficulties experienced in determining the exact age of the embryo, it has been impossible to obtain the exact curve of foetal development, and we are unable to decide whether there is a good foundation for Sömmering's opinion that it takes place by unequal bounds, with pauses and accelerations in the different months of gestation.

Preyer calculates that the length of the foetus is doubled no less than five times during the period between the fifth week and birth, and its weight from the ninth week till birth increases about 800 times, whereas the length of the body reached at birth is not even quadrupled during the whole of extra-uterine life, and its weight is only multiplied twenty-two times.

The extremes of foetal growth, which differ considerably according to race and numerous individual factors, are shown by the following table :

Age of Foetus.	Length.	Weight.
At end of 1st month	7-8 mm. (His)	Negligible.
" 2nd "	22-25 "	" "
" 3rd "	7-9 cm. (Hecker)	35 grms. (Hecker).
" 4th "	10-17 "	41 "
" 5th "	18-27 "	222 "
" 6th "	28-34 "	658 "
" 7th "	35-38 "	1343 "
" 8th "	39-43·4 cm. (Ahlfeld)	1609-2107 grms. (Ahlfeld).
" 9th "	42-48·3 "	1993-2606 "
" 10th "	45-50·5 "	2450-3168 "

It will be seen from this table that the values for both length and weight vary within somewhat wide limits. In some cases the foetus may be at full term in spite of insufficiency of weight and length. Ahlfeld saw in 1909 a new-born infant at term which weighed only 1590 grms. and was 44 cm. in length.

For the determination of the length of the foetus, measured from the crown of the head to the heel of the foot, Haase suggested the following mnemonic device as easy of application in obstetric and medical legal practice :

At the end of the first month	=	1 × 1	=	1 cm.
"	"	second	" = 2 × 2	= 4 "
"	"	third	" = 3 × 3	= 9 "
"	"	fourth	" = 4 × 4	= 16 "
"	"	fifth	" = 5 × 5	= 25 "
"	"	sixth	" = 5 × 6	= 30 "
"	"	seventh	" = 5 × 7	= 35 "
"	"	eighth	" = 5 × 8	= 40 "
"	"	ninth	" = 5 × 9	= 45 "
"	"	tenth	" = 5 × 10	= 50 "

In order to facilitate as far as possible for embryologists and physiologists the diagnosis of the age of the human embryo and foetus, I think it useful to give the table drawn up by my predecessor Jacob Moleschott, which in his own handwriting hangs on the wall of the room containing the embryological collection of the Physiological Institute of Rome. In this table it will be seen that the numerical data of foetal length and weight vary within somewhat wider limits than those given by Hecker and Ahlfeld; it also gives certain external characteristics of the embryo as guides for the more accurate estimation of the stage of development during the successive weeks and lunar months :

TABLE FOR THE DIAGNOSIS OF THE AGE OF THE HUMAN EMBRYO
AND FOETUS COMPILED BY JACOB MOLESCHOTT

First month. *Second week.*—Ovum 6·7 mm. Embryo 2·2 mm. Closure of medullary tube commenced, heart initiated; corresponds to end of first day of embryo chick.

Third week.—Ovum 13·5-27 mm. Embryo 4·5 mm. Three cerebral vesicles, three branchial fissures. Umbilical vesicle; corresponds to third day of chick.

Fourth week.—Ovum 18 - 27 mm. Embryo 8 mm. Quadrigeminal eminence, four-branchial fissures, stumps of limbs, greatest curvature of embryo; head and tail touch; closure of intestine except the orifice of the omphalo-mesenteric canal; loop of intestine projects outside the abdomen.

Second month. *Fifth week.*—Embryo 12 mm. Choroid fissure, nasal fossa, branchial fissures reduced to grooves. The embryo begins to straighten itself; hand and foot, but the humerus of the arm and the femur of the leg cannot be distinguished; the abdominal wall is closed with the exception of the umbilical ring; umbilical cord; the placenta begins.

Sixth week.—Embryo 16 mm. Branchial grooves have disappeared; nasal aperture separated from mouth, although the palate is wanting; thorax and abdomen.

Seventh week.—Embryo 20 mm. Eyelids, ears, nose, tongue; disappearance of choroid fissure; fingers and toes begin as little furrows; omphalo-mesenteric canal obliterated.

Eighth week.—Embryo 30 mm. Lips, but palate and anus are wanting; fingers more distinct; arm and forearm, thigh and leg are well defined; intestine withdrawn into the abdomen; genital groove, near it the umbilical cord; development of placenta.

Third month.—Embryo 4·5 cm.; 20-125 grms.; Pupillary membrane; palate, anus; intestine completely withdrawn into abdomen; genital groove much grown; umbilical cord not so near to it; placenta formed.

Fourth month.—Foetus 16-20 cm.; 250 grms. An epidermic veil closes the eyelids; the sex begins to be distinguishable from the external genital organs.

Fifth month.—Foetus 20-27 cm.; 250-350 grms.; epidermis, nails, hair, down, genital organs well marked. Scrotum empty.

Sixth month.—Foetus 28-32 cm.; 500 grms. Head a fourth of the body; face wrinkled.

Seventh month.—Foetus 32-36 cm.; 1 kilo.; the pupillary membrane often begins to atrophy; skin red; vernix caseosa.

Eighth month.—Foetus 40-45 cm.; 2-2·5 kilo.

Ninth month.—Foetus 45-50 cm.; 2·5-3 kilo.

Tenth month.—Foetus 50-60 cm.; 3·0-3·5 kilo.

II. At birth *foetal* life ends and that of the *new-born* child begins. Following Depaul we usually apply this term to the child during its first twenty days of extra-uterine life; it is a short period, but a characteristic one from the physiological point of view. During this period, indeed, phenomena of the utmost importance take place: the substitution of the *cardio-pulmonary* or *third circulation* for the *cardio-placental* or *second circulation*; the formation of the umbilicus; the definite establishment of the portal circulation; and the involution of the foetal blood-vessels which have become useless.

The *foetal apnoea* continues for a short time after the expulsion of the child, but is frequently forthwith interrupted by an incomplete act of respiration due to reflex action set up by the bulbar centre through the stimulating action of the cold air on the cutaneous nerves of the new-born child. This initial apnoea of the new-born child is caused by the fact that the expulsive contractions of parturition do not usually cause total detachment of the placenta from the uterine wall, hence after expulsion the cardio-placental circulation continues, at all events partially, and the blood of the new-born child has not as yet acquired that degree of venosity which is necessary to act as a stimulus capable of determining the rhythmic excitement of the bulbar centre. The apnoea lasts 20-25 seconds, in rare cases as much as 150 seconds (Bossi). It lasts longer in the child which has been easily expelled, its blood being less poor in oxygen, than in one born after a difficult labour; it is longer in premature than in mature cases, in which the consumption of oxygen is greater; and is also longer when the expulsion of the after-birth is slow than when it is rapid, because placental respiration ceases sooner.

The theory put forward in Vol. I. Chapter XIII. in explanation of *foetal apnoea* will also hold good for the *apnoea of the new-born*

child. When the placental exchange of gases between the foetus and the mother is interrupted by the detachment of the placenta, blood sufficiently arterial ceases to reach the spinal bulb, and when the venosity of the blood supplied to it reaches a certain point, the respiratory centre begins to act, and initiates the alternate inspiratory and expiratory movements. The air passes through the nose and mouth into the air passages, distends the pulmonary vesicles, and the blood of the pulmonary artery, of which the greater part went to the aorta through the *ductus arteriosus*, now goes to the pulmonary capillaries, through which begins the gaseous exchange between the surrounding air and the blood circulating through the lungs.

Owing to the diminished resistance to the passage of the blood through the pulmonary circulation brought about by the expansion of the thorax, a greater quantity of blood passes this way instead of going through the *ductus arteriosus Botalli*. With each successive respiratory movement the quantity of blood which passes into the capillaries of the lungs from the pulmonary artery increases, and the current which passes from this artery through the *ductus arteriosus* diminishes proportionately, until it finally ceases altogether. Consequently this duct is obliterated soon after birth, as was observed by P. Heger and Marique in forty-seven children, thus confirming the previous observations of Heller. According to Costa Alvarenga (1870), the transformation of the *ductus arteriosus* into a fibrous cord is completed at from the second to the fifth month; Walkhoff (1879), however, who studied its histological modifications, considers that the transformation is accomplished as early as the twentieth day after birth. It is facilitated by the speedy formation of an occluding thrombus, and is completed later by proliferation of the intima, in which even before birth the sub-endothelial layer is unusually developed.

Corresponding to the greater flow through the pulmonary artery there is a steadily increasing flow of blood towards the pulmonary capillaries where it changes from venous into arterial blood, returning to the left auricle through the pulmonary veins.

At the same time, owing to the cessation of the flow of blood from the umbilical vein through the *ductus Arantii*, the outflow from the inferior vena cava is diminished and the blood in the right auricle, meeting with little resistance in the direction of the right ventricle, which now rapidly discharges its contents into the pulmonary artery, finds in the left auricle, now filled with blood from the pulmonary veins, an obstacle to its passage through the *foramen ovale*. The increase of pressure in the left auricle creates a condition favourable to the closure of the foramen. It is obliterated by means of a valve which makes its appearance in the human embryo towards the eighth week, and develops in front of the *Eustachian valve*, of which it seems to be a prolonga-

tion (Fig. 116). It advances from behind forward along the left face of the inter-auricular septum, extending at birth with its anterior free border beyond the circumference of the foramen ovale. When the pressure in the left auricle increases, the valve is distended and applied to the orifice of the foramen, and finally closes it up. The whole of the blood of the right auricle coming from the two venae cavae must then pass into the right ventricle below, and the *third*, or *cardio-pulmonary circulation*, is thus definitely established.

The umbilical arteries in the interior of the body are obliterated as far as the sides of the bladder between the fifteenth and the twentieth day, after contraction within their sheaths, and are finally transformed into the *lateral ligaments of the bladder*. A similar change occurs in the *ductus Arantii*, which becomes the *ligamentum teres of the liver*.

The normal foetus at the end of pregnancy weighs, as we have already seen, on an average 3200 grms. and measures about 50 cm. in length. During the first three days after birth it loses about 250 grms. in weight, but regains its original weight between the tenth and the fifteenth day.

Even within physiological limits there are many circumstances which influence the weight and length of the foetus: amongst others the bodily development of the father (La Torre); the age and bodily development, more especially of the pelvis, of the mother (Fasola and Bertazzoli); multiparity; and the sex of the foetus, the males being longer and heavier.

There also seems to be a direct relation between the quantity of the amniotic fluid, the length of the cord, the weight of the placenta, and the weight of the foetus (Zentler, Smith). Duncan considers that the weight of the new-born infant increases with the age of the mother up to the 29th year, and the length up to the 44th year. According to Wernich, the children borne by a woman who menstruated early are, *ceteris paribus*, heavier than those borne by one who menstruated late. Cuzzi found that the weight of the child increased with the duration of the menstrual haemorrhage of the mother; according to Hecker, in the case of successive pregnancies the bodily development of each offspring is superior to that of its predecessors, although, as was pointed out by Wernich, this rule does not hold when the intervals between one pregnancy and the next are either too short or too long. From these observations a corollary of practical value may be deduced, since the size of the foetal head depends, within certain limits, on the weight and length of the foetus (Ahlfeld, Budin, Ribemont).

We will pass over the minute external characteristics by which the maturity of the new-born child may be estimated, merely bearing in mind that the upper half of the infant is always better developed than the lower, because—as we have already remarked—

the upper half is nourished by blood which is more arterial and richer in histogenic substances.

When the placental circulation is suppressed, the umbilical scar begins to form; in the new-born child this scar is situated about half way down the body (Bigeschi) or a few centimetres lower down (Bongiovanni, De Billi, Belluzzi, and Pilla), usually nearer the pubic symphysis than the xyphisternum (Hecker).

The lungs of the foetus at the ninth lunar month are fully formed (Hertwig); after birth the size of the alveoli increases and the cylindrical epithelium with which they are lined becomes flattened owing to the distension. Whereas before birth the lungs weigh 60 grms., those of the new-born child weigh about 90 grms., the difference being due to the blood with which the capillary network is filled (Gillis). The *lung test* of Daniel and Ploucquet (1782) is based upon the increase in the volume of the lungs caused by the distension of the alveoli with air.

The heart of a new-born child weighs 15 grms. and, as in the case of the quantity of blood, is greater in proportion to the weight of the body than that of an adult. It beats at the rate of 120-140 a minute, so that the whole circulation takes place in less time than that of the adult, and the renewal of the blood in the capillaries of the tissues is extremely rapid.

The establishment of the cardio-pulmonary circulation brings about other modifications in the composition of the blood and more particularly in the structure of the corpuscles. According to Raibaud and Vernet (1904), the *polynuclear neutrophile* leucocytes predominate in the first day of extra-uterine life, whilst during the first year of life there is a *physiological mononuclear leucocytosis*.

The digestive system is adapted to the milk diet. The saliva of the infant is scanty until teething begins, and has very little action upon starch. The stomach has a very slightly developed great curve; it is almost vertical and possesses little tone in the cardiac sphincter and thus regurgitation is facilitated. Its capacity at birth varies from 25 to 30 c.c. according to the weight of the body; its secretion is small in quantity and contains very little hydrochloric acid; it does, however, contain pepsin and is capable of peptonising proteins (Reeve-Ramsay, 1908).

The intestines are more highly developed in proportion to the length of the body than those of the adult; the length of the small intestine being 287 cm., that of the large 56 cm. The meconium which has accumulated in the last section of the small intestine and in the large bowel to the amount of some 75 grms. at the time of birth is at once discharged by the infant.

At birth the right lobe of the liver is far the most highly developed; its weight varies, Hecker estimating it at 128 grms., Gillis at 180 grms, and it bears to the weight of the body an average ratio of 1 to 8.

The spleen weighs 9 grms. at birth; Malpighi's corpuscles make their appearance only at the close of intra-uterine life. The secretion of the pancreas at the time of birth has a slight amyolytic action. Owing to the weak digestive capacity of the new-born infant, the faeces contain many undigested organic substances, such as casein and fats, as well as undecomposed bile pigments and salts.

The kidneys are perfectly developed in the new-born child, although they present an irregular lobular surface; on an average each weighs 11 grms. The quantity of urine, which is small during the first two days, increases greatly in proportion to the weight of the body at the end of the first week, a change due either to the liquid diet or to the active metabolism. Not only the quantity of urine, but also that of the urea and other nitrogenous or non-nitrogenous constituents is proportionately greater in the case of the infant than in the adult; the phosphates, and more especially phosphates of lime, which are retained for the construction of the bones, are, however, scanty.

The skeleton of the new-born child is still partly cartilaginous. Of the various points of ossification we would call attention to the one corresponding to the lower extremity of the femur (known as the *nucleus of Blecard*), which is important as a criterion of the development of the foetus.

At birth the formation of the brain, which weighs about 350 grms., is complete, and according to Kölliker the number of its convolutions and accessory folds is so great as sometimes to exceed that of the adult. The first complete nerve-cells make their appearance in the spinal cord and inter-vertebral ganglia and are those which form the roots of the spinal nerves. By their means are effected the first reflex acts, the simplest movements of the foetus up to the fourth and fifth months of intra-uterine life. Later on, when the foetus measures 40 cms., the cells of the column of Goll are completed, by means of which peripheral stimuli are transmitted along the whole length of the spinal cord to the lower portions of the bulb. The eighth month sees the complete development of the fibres of the tract of Gowers, which extend to the upper grey matter of the brain, the optic thalami, and the cerebral cortex; thus the sensory paths are opened. Even before birth the conditions necessary for the rudiments of psychical life have come into being, and the child when it first comes into the world, and even before it opens its eyes and ears, has ceased at least in the physiological sense to be the *tabula rasa* or blank page of certain philosophers. On these foundations the sensory and motor areas of the cerebral cortex are built up, and between them spread the association fibres and centres.

We may remark in passing that the nervous system of the child is more excitable than that of the adult; this may be due

either to the slight and imperfect morphological differentiation or to the constitution of its chemical components. Cohn (1907) says that during the first year of life the development of the brain is carried on at the cost of protein substances, whereas the constituents containing phosphorus diminish slightly, and the quantity of calcium contained in the cerebral substance is notably less, more particularly during the last period of foetal life and the first months of extra-uterine life. Tetany during childhood is, according to Quest, associated with an abnormal lack of calcium in the cerebral matter.

The sense of touch, temperature, and pain are well developed in the new-born infant; this is also the case with taste and perhaps also with smell. The pupil is larger than in the adult. The infant born at full term shows a distinct movement in *response to light*, although central vision is not as yet established and several weeks must elapse before the infant's eyes are capable of looking steadily at any object. Magitot (1909) noticed the above-mentioned reflex in children born prematurely, a proof that the optic nerve is capable of transmitting the stimulus to the centres even before its fibres have been provided with their medullary sheath.

The auditory sensations in the new-born infant are extremely dull and confused; this is due to the fact that the middle ear is stopped up with an amorphous gelatinous substance, which fits into all the crevices of the tympanic cavity and disappears with the first breaths (Gellé, Giovanardi, Wreden). The cavity of the tympanum is therefore purely potential at the moment of birth, and is first formed when the respiratory movements facilitate the absorption of the lymph which renders turgid the sub-mucous membrane lining the tympanum. The mucous surfaces recede from one another, thus making pervious the hollow of the middle ear which is filled with air by the Eustachian tube; when this cavity is sufficiently large, the membrane of the tympanum is able to vibrate and to transmit the vibrations to the fenestra ovalis by means of the chain of ossicles. Hence the new-born child is deaf and only acquires the sense of hearing gradually after five or six days of life (Preyer, Poli). Thus sensations are developed gradually by successive experiences.

III. The age of childhood is, in the strictest sense, *the period of growth*. It is true that during intra-uterine life, adolescence, and youth the individual increases both in size and weight, but foetal life is more especially the period of the creation of tissues and organs, whilst in adolescence growth is somewhat less marked than in infancy and is subject to interruptions. During childhood, on the other hand, growth is progressive; it is most rapid during the first stage of infancy and gradually diminishes during the successive stages of childhood. If we estimate the differences

between the new-born baby and the child who is nearing puberty, we are driven to the conclusion that no other period of extra-uterine life shows such a far-reaching functional transformation and such a rapid development of the body as the brief period of infancy. The period of growth *par excellence* is infancy, and if we would determine the characteristics of infantile life, we must have some notion of the theory of growth.

In every species, race, and family growth takes place in accordance with certain laws of evolution resulting from biological forces which are transmitted with the hereditary patrimony. Certain external conditions, such as nourishment and mode of life, may modify growth within certain narrow limits, but the influence of these factors is a negligible quantity compared to that of heredity. When treating of the problem of the transmission of the characteristics of parents to their offspring, we saw in Chapter V. that science is unable to account for it and can only hazard certain vague and bold hypotheses by way of explanation. We are ignorant of the physical conditions which bring about the multiplication and cellular differentiation of the germ resulting from the fusion of the two sexual elements until in course of time it assumes a typical form and becomes a determined organic mass which is almost constant in the individual species and varieties. Here we have the baffling problem formulated by Aristotle in the following words: "*causae explicandae sunt, quoniam animalium alia longum aetatis tempus conficiant, alia breve.*"

We have learnt but little of the *primum movens* of cellular multiplication since Haller's day; Loeb by the use of chemicals (hydro-chlorate of manganese) succeeded in exciting the first phases of development in eggs of echinoderms and annelides. He regarded the nucleus of the cell as a *ferment for its own synthesis of nuclein*, and believes that the autokatalytic character of this synthesis is the basis of the hereditary continuity of life. Ostwald and Robertson have endeavoured to prove that the curves of growth, *i.e.* of the gradual increase in weight and cellular multiplication of organisms, assume the aspect peculiar to autokatalytic reactions. These ingenious hypotheses fail however to explain why the fertilised ovum should in the course of its development tend to reproduce in the offspring the specific form of the parents, their features and sometimes even certain of their peculiarities.

On the other hand, Max Rubner has enabled us to lay down certain laws to which growth in relation to the exchange of material and energy is subject once it has been begun by fertilisation. It is governed by two fundamental facts:

(a) *No animal cell can grow and multiply without developing heat.* Rubner calculated for the foetal life of mammals the number of calories which can be developed during the formation

of a given mass of living substance, and arrived at the following results: the horse, 2028; the pig, 2210; the sheep, 2728; and the dog, 3318. In the case of man the figures must be higher owing to his longer period of development.

(b) *Consumption and destruction of substance always coincide with the phenomenon of growth.* The researches of Parrot and Robin (1876) prove that a new-born infant for a given weight absorbs more oxygen and twice as much nitrogen as the same weight of an adult and discharges only a sixth of the amount of urea, because a large portion of the nitrogen is retained for the requirements of growth. On the other hand, dissimilation is very active in the new-born, and the kidneys in proportion to the weight of the body are twice as large as those of the adult.

Rubner gave the name *quotient of growth* to the percentage relationship between the sum of accumulated energy, deduced from the increase in weight, and the sum of energy consumed in the process of dissimilation. This quotient is very high after birth; it decreases until it reaches zero in the higher animals, whereas in unicellular creatures it appears to be an invariable constant.

The determination of this quotient in the animal scale brings out an unexpected fact, namely, that the consumption of energy in the processes of disintegration, which are more intense in the growing than in the resting cell, is much greater than the energy expended on growth.

Rubner states that the different organisms use different quantities of nutritive material for the increase of their body weight. The Schizomycetes, which can double their size in a few minutes, accumulate during growth 12-31 per cent of the total energy introduced. The definite size of an animal is, however, not only dependent upon the length of the period of growth, but is also bound up with specific and individual properties.

If with Rubner we consider the time taken by the new-born animal to double its weight, we find the rabbit takes 6 days, the dog and cat 9, the pig and sheep 14-15, the ox 47, the horse 60, and man 180. If, therefore, man as compared with the rabbit takes thirty times as long to double his own weight, he must consume a correspondingly greater amount of nourishment in order to acquire a similar weight of body substance.

If we calculate the energy consumed in the time during which a kilogramme of new-born animal doubles its own weight and express the result in calories, we arrive at the following figures: horse, 4512; ox, 4243; sheep and pig, about 3800; dog, 4304; rabbit, 5066; man, 28,864. Thus the total amount of energy expended in doubling the weight of the animal is much the same irrespective of the length of the period of growth, except in the case of man, whose consumption of energy is much greater.

In the determination of the amount of energy contained in the food used for the purpose of growth, Rubner found that whereas the above-mentioned animals absorb during the first period of doubling their own weight on an average 34.30 per cent of the calories introduced, man stores up only 5.2 per cent, *i.e.* hardly more than a seventh.

Man further differs from other animals in the length of his intra-uterine development, which in other animals usually increases with the rise in the body weight. Thus the young of man and the sheep weigh the same at birth, but the foetal life of the sheep is only half as long as that of man and the difference in their development during extra-uterine life is still more marked.

The extent and different kind of growth of animals are determined after fertilisation, for the exchange of material in the ovum does not differ much from that of the cells of the maternal organism, whose consumption of energy varies especially in proportion to the total size. After fertilisation the ovum shows an exchange of material varying according to its origin and the period of development of the organism arising from it will also differ. With fertilisation all cells acquire the maximum quotient of growth, but after birth the energy of growth gradually diminishes each time the mass of the body is doubled until it reaches zero and the animal attains its full size.

Bodily growth is undoubtedly brought about by the exchange of material and energy in the new-born animal; an animal in which metabolism takes place more rapidly will double its weight in a shorter time and build up in that space of time the same amount of substance as an animal, in which metabolism takes place more slowly, would in a longer period.

From the facts which we have enumerated it is obvious that man occupies a unique position as compared with other mammals; his increase in size during his intra-uterine life and the whole of the anaplastic stage is small in proportion to the intensity of his exchange of energy. Rubner notes another interesting point: that man differs from other mammals in the total amount of energy used in a state of rest after the expiration of the anaplastic period.

Animal.	Weight in Kilos.	Duration of Life, in Years.	Duration of Growth, in Years.	Duration of Life after Growth, in Years.	Production of Calories per Kilo of Live Weight after cessation of growth.
Horse .	450	35	5	30	163,900
Ox .	450	30	4	26	141,090
Dog .	22	11	2	9	164,000
Cat .	2	9.5	1.5	8	223,800
Man .	60	80	20	60	725,800

These figures show that a kilogramme of living animal matter consumes much the same amount of energy after the period of growth, and since this is also the case during the period of growth, we may fairly conclude that in the higher animals the total amount of energy consumed is as nearly as possible the same throughout life. Man alone stands above the other animals examined in the capacity shown by his living substance for developing a quantity of energy which is relatively much greater. The fact that man grows more slowly than other mammals, lives longer and consumes a greater amount of energy implies that his metabolism proceeds in a different way from that of other animals, probably owing to the higher cerebral development attained by him.

Growth stamps the organism with a certain number of physiological characteristics, especially with regard to the tissues and organs.

At birth the child has all its organs, some of which, the thymus, for example, are fated to disappear, but they are imperfect in size, shape, function, and structure. They attain the adult state by means of a series of histological changes, such as *hyperplasia* or cellular proliferation, *hypertrophy* or increase in cellular volume, and *differentiation*, which transform the initial homogeneous elements into cells highly specialised in the morphological, physico-chemical, and physiological sense.

The epithelial and lymphoid tissues always retain—so Bizzozero asserts—the power of increasing and renewing themselves by *hyperplasia*; the connective, cartilaginous, and bony tissues, the smooth muscular fibres, the tissue of the liver, pancreas, kidneys, and salivary glands grow by *hyperplasia* during foetal life and the first period of extra-uterine life, and by *hypertrophy* during the later periods; the striated muscular and the nervous tissues grow by *hyperplasia* only at the beginning of embryonic life and lose this power before birth; the muscular fibres and nerve-cells, the true permanent structures, increase during extra-uterine life by *hypertrophy* only, and may undergo *differentiation*.

One important fact which the study of development brings out is that the growth in the different parts of the organism does not proceed on parallel lines; in the same individual the organs and systems do not reach the adult stage at the same time.

In order to follow the progress of construction as a whole in the living individual, we must have recourse to the criteria afforded by weight and height and in recent years by the radiographic study of the bones.

From birth to early maturity the human body grows to about three and a half times its original height, while its weight increases about twenty-fold. The height of a child increases by half as much again during the first year of life; it measures about 50 cms. at birth and 70 to 80 at the end of the first year; at six years old

its height is more than double that at birth. During the following years there is a growth of 50 to 75 cms., the full height being attained between 20 and 25 years of age. Growth is not uniform and continuous, but is slower at times, and even checked altogether for a time, only to begin again suddenly.

MacDonald prefers to estimate individual growth by the criterion of weight, though many causes, such as obesity and disease, tend to make this unreliable.

The increase in weight equally with that of stature is subject to fluctuations, but they do not however correspond to one another. During the first months the infant increases very rapidly in weight, but this rate is not maintained. At the end of the first month the weight is almost twice, at the end of the first year it is more than three times as much as that at birth.

Th. Rotch (Boston) distinguishes in children the *chronological* from the *anatomical age*, inferred from the phases of the development of the bones, which he regards as connected with the physiological conditions of the organism as a whole. From radiographs taken of different parts of the body of over 500 children in conditions apparently normal, Rotch came to the conclusion that the successive appearance or development of the *carpal bones* may be taken as *an index of anatomical growth* in order to determine the different periods of childhood.

IV. *Childhood* lasts from birth to puberty. As a rule, authorities on the subject (Marfan, Vierordt, and others) recognise, apart from slight divergences, three periods.

(a) *Early childhood* or *infancy* comprises the first two years of life, with the exception of the brief phase of the new-born child which we have already studied. During the first year the child has no teeth and lives entirely on milk, it neither speaks nor walks, its psychic acts are rudimentary, involuntary reflex actions predominating, and it falls asleep readily after it has been fed at the breast. In the second year the purely milk diet ceases, and the child begins to stand, and little by little to walk; with the development of the visual and auditory sensations begin the first signs of psychic life and the manifestation of that life in the gradual development of articulate language. The salient characteristic of this period is rapidity of development (which as we have already seen is greater than during any other period of life) and the appearance of the *first dentition*. The *lower central incisors* are the first to be cut at about seven months; at about two and a half years of age the four last *premolars* appear, and the child now possesses twenty teeth, which form the temporary or *milk teeth*.

(b) The *second* or *middle period of childhood* lasts from the second to the fifth or sixth year, that is until the *first four large permanent molars* are cut, with which the *second dentition* begins

(the *front incisors* do not begin to fall out and the second ones to appear till the child is seven years old).

During this second period mastication takes the place of suction, and the child's diet is more like that of an adult; he walks more and more steadily, and his movements are quick, easy, and exuberant; his psychic life is lively and tumultuous, and his fluency of speech correspondingly greater. During this second period, earlier in girls than in boys, the *secondary sexual characteristics* begin to appear, so that from the figure as a whole and the bodily development, the sex may be guessed without evidence concerning the sexual organs.

Fürst describes a state of relative anaemia as occurring at the close of this period (from 5 to 7 years of age) and coinciding with excessive thinness and rapid increase in height; to this he gives the name *anaemia of growth*.

(c) The third period of *childhood* (*boyhood* or *girlhood*) lasts from the sixth or seventh year to the age of puberty. When the second teeth have been cut, from seven years old onwards, it may be said that all the other organs and tissues, with the exception of the generative cells which are still undifferentiated, have attained almost the same relative stage of development and that their further growth will proceed on parallel lines. This period presents no characteristics necessitating its subdivision into stages; its length varies with climate and various racial and social conditions. In our climate it ends with puberty in girls at from 13 to 15 years of age, in boys at from 15 to 18 (see Chapter V.). Basing his conclusion on 31,659 cases, Rossi-Doria (1908) has established the average age for Italian girls at the time of the first menstruation as 14 years, 5 months, and 22 days. From the anatomical point of view, however, the body in our race only attains its full development later, as is also the case with the sexual functions. Lange considers that the female body ceases to grow at 19 years of age, the male at 20; there are, however, numerous cases of women whose maximum growth has been reached at 24 to 28 years of age and of men at 30 to 34 years, though growth after the twentieth year is slow and limited. In Chapters IV. and V. we have already treated of the general and particular changes which mark the beginning of puberty in the two sexes.

Various authors have endeavoured to establish by measurements the average growth. These investigations, which were begun by Quételet, the director of the statistical office in Brussels, on the infant population, were repeated by Bowditch on the children of Boston, and carried further by Pagliani, Geissler, Ultzsch, and Daffner. The averages obtained by the different authors vary considerably. Stratz distinguishes *normal values for growth* (which are probably higher than *average values*)

obtained by selecting individuals free from bodily defects and extending from the average size (50 cm.) of the normal newly-born infant of the white race to that of the strong healthy adult of 25 years of age (man 180, woman 170 cms.). Thus we obtain the total increase in height represented by 130 cms., or 3.6 times the original height.

According to Quételet the increase over the size at birth is for the head twofold, the trunk threefold, the arm fourfold, and the leg fivefold, whilst the whole figure attains a height $3\frac{2}{3}$ as great as the original.

As Stratz has pointed out, there is no fixed rule for the annual growth, some children growing quickly, others slowly, and some apparently stopping altogether at certain periods which recur with a certain irregular rhythm. Mulling Hansen's researches tend to show that these great oscillations in growth are reproduced on a smaller scale in the course of the months and weeks and even of the hours of the day. Thus growth in autumn is not the same as in spring; there are three periods of increase in weight every year, one, from the beginning of August to the middle of December, in which the increase is rapid; the second, from the middle of December to the end of March, in which the increase proceeds more slowly; the third, from the beginning of April to the end of July in which it almost ceases. The same alternation, but inverted, is noticeable in increase of stature. Whereas the weight increases by day and decreases during the night, the reverse holds good for the height. The fluctuations are slight (500 grs. 10 mms.), but not devoid of importance.

The Danish pedagogue we have just quoted, who is an adherent of the theory of environment as opposed to that of heredity as a factor in the development of the child, explains these variations by their dependence on the influence of the solar rays, temperature, the alternation of the seasons—an influence which is seen in the rhythmic oscillations of growth in vegetable life and also in the animal world.

The *average curves* of growth in weight and height, such as those constructed by Pagliani and reproduced in the two upper curves in Fig. 120, show that up to 9 years of age boys are heavier and taller than girls; during the next four or five years they are smaller, but become taller and heavier again after their fifteenth year. Pagliani attributes this to the fact that growth is very rapid during the two years before puberty and becomes much slower afterwards. Since the age of puberty in women is two to three years earlier than in men, it follows that the period of most rapid growth is earlier in girls than in boys.

As regards vital capacity and muscular strength, the relative curves, Fig. 120, prove that they are always greater in boys than girls, and the difference increases after puberty.

The four curves shown in Fig. 121 represent the course of growth in weight and height of boys and girls from 8 to 19

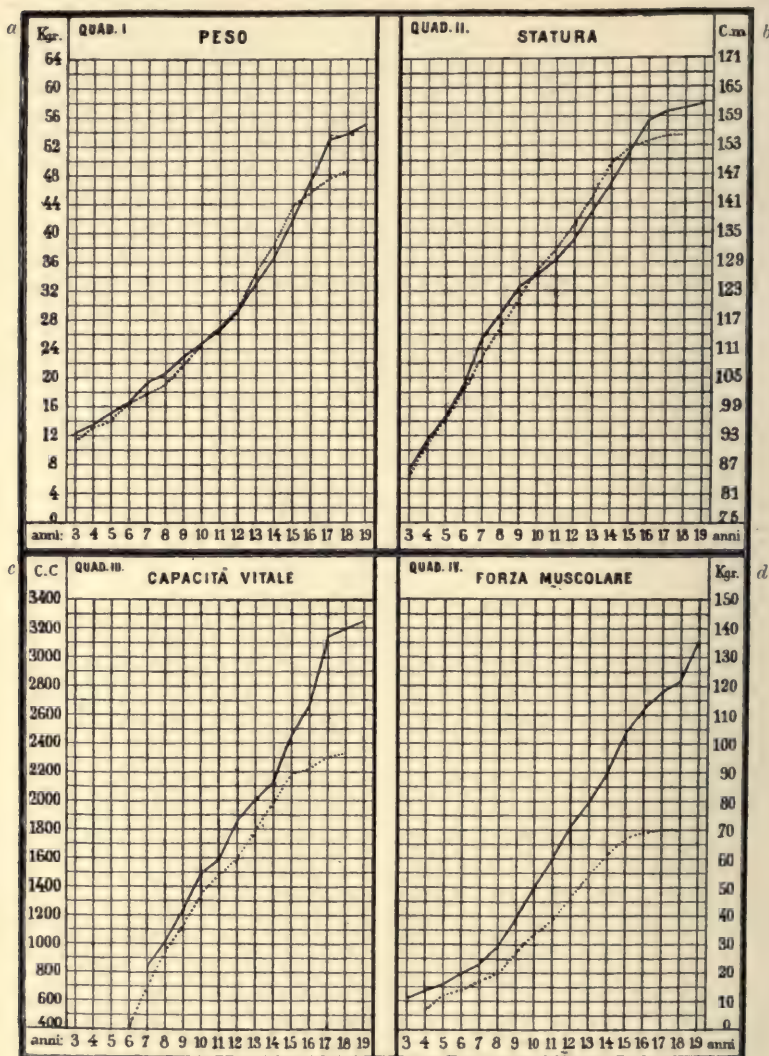


FIG. 120.—Curve of growth of man according to age and sex. (Pagliani.)

Males=—————

Females=.....

a, weight; b, height; c, vital capacity; d, muscular strength.

years of age, arranged according to whether they belong to poor families or to those in comfortable circumstances. They

show that the average is definitely higher in the members of

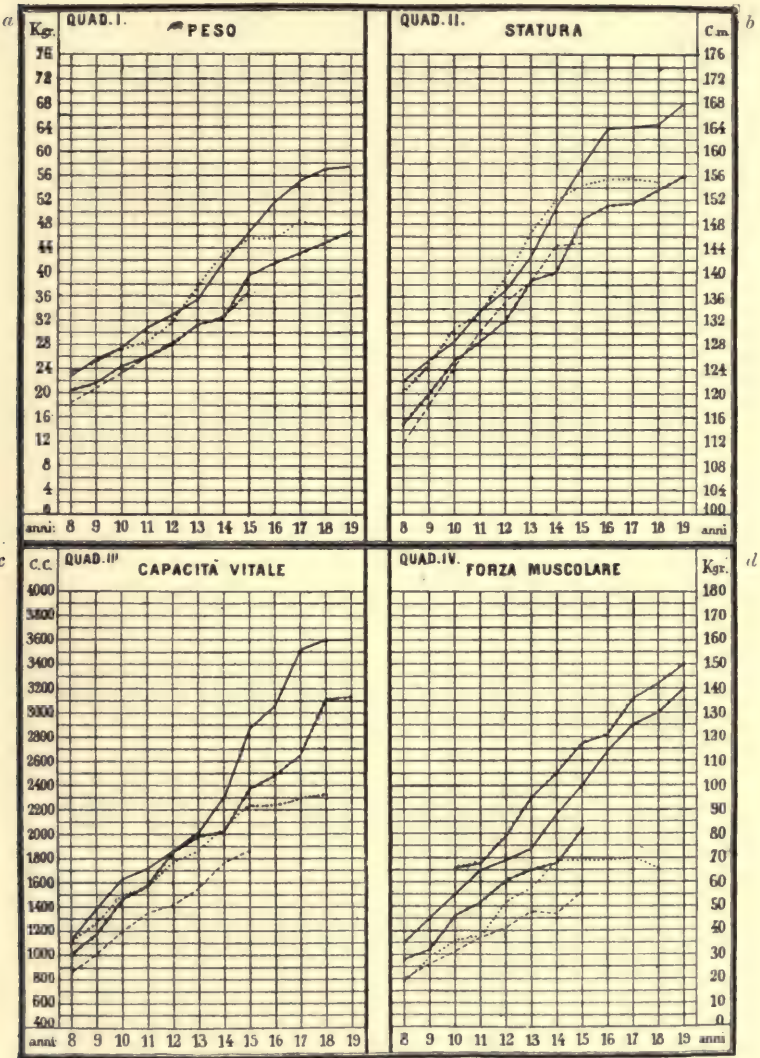


FIG. 121.—Curve of growth of man, according to age, sex, and social position. (Pagliani.)

Well-to-do Class { Males ———— Poor Class { Males { Town - - - - -
 Females Females { Country - - - - -

a, weight; b, height; c, vital capacity; d, muscular strength.

prosperous families than in those belonging to families in poor circumstances.

In every case in boys a rapid increase in stature is associated with a slow increase in weight and bulk. Children, especially those who are plump and blooming during their first years, gain rapidly in height at the end of their third or fourth year, but they become at the same time thinner and less robust; this is the period of the first *increase in height*. Between the eighth and tenth year there is generally observed a new period, known as the *second increase in height*.

In order to form an idea of the way in which the proportions of the body vary during growth, we may take as a working basis the relation which is almost constant between the length of the head and that of the body. The total length of the child at birth is four times that of the head; at two years of age it is five, at six, six; at fifteen, seven; and in the adult eight times as long. This is shown by the following table, which may be regarded as the standard of average measurements:

Stages of Life.		Age.	Length of Head.	Height in cms.
Non-sexual or neutral life of early infancy.	{ Period of first growth in bulk. (<i>Turgor primus.</i>) }	New-born.	4 times.	50
		One year.	4½ "	75
		Two years.	5 "	
		Four years.	5½ "	
	{ Period of first increase in length. (<i>Proceritas prima.</i>) }	Five to six years.	6 "	100
Bisexual life of second and third periods of childhood.	{ Period of second growth in bulk. (<i>Turgor secundus.</i>) }	Six to ten years.	6½ times.	125
	{ Period of second increase in length. (<i>Proceritas secunda.</i>) }	Eleven to fifteen years.	7 to 7½ times.	150
Sexual life of maturity.	{ Period of puberty. }	Fifteen to twenty-four years.	8 times.	180

At the beginning of puberty the increase in height is very small; on the other hand, the increase in weight is very great (Pagliani), being in the next two or three years about twice as great as before; for this reason some physiologists apply the term *turgor tertius* to this period. Later on the increase in weight becomes normal again, and from the fifteenth year in girls and the seventeenth in boys, when the weight at this age reaches 50 kg., the increase becomes gradually less until maturity is

attained at 25 years of age, when it ceases altogether, except in cases of excessive corpulence.

The transition from adolescence to youth does not present the same features in every case, but varies considerably owing to different causes.

The longer the process of development, the more perfect it is; the longer the human being remains a child and the later the sexual functions and characteristics make their appearance, the more complete will be his development as a whole. The right kind of home and social environment, a wise and careful upbringing, can do much towards postponing the use and possibly also the development of the sexual organs, a fact which is of the greatest interest from the educational point of view.

V. The *adolescence* of the Latin races, which begins with the variable age of puberty, comprises the whole process of development of the organs and organism both in stature and weight, and also those physical and psychical changes which go with that development. In the case of women it lasts until the age of 21, unless puberty be unusually late, and in that of men until 25 to 28 years of age. The term *adolescence* is most correctly applied to the first stage of this period; after puberty man enters the period of youth, the age of full activity, during which he develops the capacity for useful work, and becomes fit for military service.

At this age, when the physical and aesthetic characteristics of the body have reached perfection and the sexual tendencies are properly developed, man is conscious of a new feeling of vigour and expansive ability which decides his walk in life.

The slight, supple figure of the young woman or man attains that outward perfection of which the Greeks gave us the model in their statues of Diana and Apollo. The skin loses the delicacy of childhood, the hair becomes richer in colour, the muscles become larger and firmer, imparting the final shape and size to the limbs and endowing the whole body with agility, flexibility, grace, and strength. The head is no longer disproportionate in size as in childhood, and with the increase in the thorax and the pelvis harmonious proportions are established between the three portions of the body. The lymphatic plethora peculiar to childhood decreases and the right equilibrium is attained in the proportion of blood and lymph. The strength of the heart increases, the arteries and veins are elastic and large, so that the flow of blood through the whole capillary network is at its strongest in youth. The respiratory movements, in agreement with the increased size of the lungs, are slower and less frequent than in the preceding years. The digestive system attains its full activity; the masticatory apparatus is completed by the addition of the four last molars, the so-called *wisdom teeth*. The absorption of the digestive

products is in proportion to the development of the muscles, the solidification of the osseous system, the increased activity of the exchange of material and energy, and the perfected thermal economy.

To these general characteristics of the youthful organism must be added the important modifications brought about by the well-known secondary sexual characteristics of the male and female. The features become more marked and reflect the thought and affections; the sensations in youth acquire the variety and delicacy of which the organs of sense are capable; youth is the age of sharp and easy perception, reliable memory and vivid imagination. During this period the power of concentration is perfected, the aesthetic taste and the ethical sentiment of social life are formed. The youth, conscious of his powers, both present and to come, is apt at times to be rash and thoughtless; his lack of experience frequently leads him into difficulties, so that we see the truth of the French saying: "si jeunesse savait, si vieillesse pouvait."

Youth merges into *maturity* (termed *manhood* in man), but the transition from the first to the second stage is gradual and not characterised by any special functional or morphological change. Women are, however, commonly supposed to attain *maturity* at the age of twenty-one, though the law looks upon them as *marriageable* from the age of puberty. Men, on the other hand, attain their full strength and will-power at the age of twenty-five. It is during this period that the man usually founds a family and the woman enters upon her maternal functions, with all the attendant local and general phenomena which we have discussed in the preceding chapter. As we have already seen, fecundity in women lasts till about fifty years of age, and in men till sixty and later, there being no absolute limits in this respect. The cessation of growth (Quételet), the full development of the whole organism, together with its physical and moral capacities, rendering man sufficient unto himself and free to do as he chooses, the final constitution of his temperament, that is to say, of the relation between his physical and moral nature, fitness for generation and the higher development of the psychic functions, are one and all characteristics of virility. The human parabola has reached the culminating point depicted by Michelangelo in "The Dream of Life."

The drawing of the perfect adult man and the measurements for the proportionate development of the different parts of the body (given by Leonardo da Vinci) for the assistance of painters and sculptors may also be of interest to my readers (Fig. 122).

The destiny of the individual and his functions in relation to the society to which he belongs are for the most part decided during this relatively permanent period of equilibrium in body and virile energy.

Although man's mental powers suffer less from the passing of the years than does his muscular strength and frequently remain unimpaired when his body has ceased to be capable of the lightest manual labour, history shows that men of science have made most of their great discoveries and written their most important works, which form the patrimony of our civilisation, during the period of virility, between their fortieth and their sixtieth year; for this statement we have the witness of history. Amongst such works are Galileo's *Nuncius sidereus*; Linnaeus' *Species plantarum*; Newton's *Principia*; Descartes' *Discours de la méthode*; Kant's *Kritik der reinen Vernunft*; Lamarck's *Philosophie zoologique*; Mueller's *Physiologie des Menschen*; and Darwin's *Origin of Species*.

The long period of maturity or virility, the most important and the longest in life, is usually subdivided into three stages:

(a) *Increasing virility*, termed by Sallust and Cicero *juventus*, during which the constitution and physical powers are being brought to perfection; it comes to an end between thirty and thirty-five years of age in women, but lasts until forty in men.

(b) *Stationary virility*, termed *actas constans* by the ancients, during which the organism and powers remain unchanged; it lasts from the thirty-fifth to the fortieth year in women and from the fortieth to the fiftieth in men.

(c) *Decreasing virility*, from the fortieth to fiftieth year in women and the fiftieth to the sixtieth in men.

In the case of women the end of maturity coincides with the end of fecundity—the cessation of menstruation. Though this is the most noticeable symptom of this stage, it is by no means the most important, since it is accompanied by great changes in the organism. In all languages we find popular expressions for the organic disturbances, the dangers and inconveniences connected with the end of sexual life (*critical age*, *climacteric*, etc.). We have dealt at length with these disturbances in the preceding chapter. The order in which these morphological and physiological phenomena of the menopause take place varies in different women. Hegar, when treating of the changes undergone by the genital organs, considers that atrophy of the ovary precedes that of the uterus, and adduces as an argument for this theory the fact that fecundity diminishes gradually before menstruation ceases. Lawson Tait, on the contrary, is of the opinion that ovulation may last long after this cessation, and thus admits the possibility of conception during the change of life. Ovaries normal in size and structure have been found several years after the menopause (Peuch, Mangiagalli), a proof that the cessation of menstruation is no indication that the atrophy of the ovaries, as far as their essential characteristics are concerned, has reached its extreme limits.

Various physiological factors, such as race, heredity, sexual

activity, climate, social conditions, may hasten or retard the beginning of the menopause, just as they influence the advent of puberty, that is the appearance of the first menstruation. It is generally supposed that very early menstruation causes the change of life to take place earlier, "*prius pubescentes, prius senescunt*" (Virey); on the other hand, observation proves that numerous conceptions make it take place later.

Taking the statistics drawn up by Mayer, Tilt, Guy, and Peuch, we find that the change of life takes place :

At from 35 to 40 years of age in 12 per cent of women,					
" 41 to 45	"	"	26	"	"
" 46 to 50	"	"	41	"	"
" 51 to 55	"	"	15	"	"

and in 6 per cent either before or after these limits.

We may on the whole adopt Kisch's view that the menstrual function begins later and lasts longer in northern countries; that scanty menstruation and moderate sexual activity tend to retard the change of life, whereas too early sexual relations, childbirth at too short intervals, and unhealthy confinements bring it about sooner; also that favourable conditions as to nourishment and social environment prolong the menstrual period.

Some writers, Halford, Church, Mendel, De Fleury amongst others, are of the opinion that in men too a number of disturbances take place at about fifty years of age which they regard as equivalent to those of the change of life. They have noticed in individuals who showed no signs of mental weakness or arteriosclerosis, and up to this age were well-nourished and enjoyed excellent health, a sudden and rapid deterioration of the whole organism, usually only of a temporary nature. This seems to be a critical period, which, beginning with gastric and cardiovascular disturbances, affects all the other functions. The patient's character changes, he suffers from depression and fears, complains of anxiety and restlessness, feels weak, and notices a failure of memory and decreased sexual desire. Other symptoms are: sudden congestion of the head, a feeling of oppression with sudden breaking into perspiration, palpitation of the heart, insomnia, giddiness, headaches, multiple paraesthesia. This supposed *critical period* covers a period of from ten months to four years, and is attributed by Mendel to a diminution of the secretions (internal or external?) of the glands of the generative system. The theory is very suggestive, but does not seem to me to rest on a sufficiently large number of scientific observations which cannot be explained as casual morbid symptoms, arising from quite other causes than those suggested by Mendel.

VI. After the period of youth and maturity comes that of the decadence of the organism. Growing old is caused by the nature of the exchange of material and energy in the living

protoplasm, which undergoes slow and continuous change during life, in the sense that the functions of restoration, repair, and compensation gradually become less perfect and less complete, until finally all vital activity ceases.

We may say positively that the *cataplastic phase* of life is absolutely physiological; it corresponds with the natural decline of every living being, which inevitably ends in death, the completion of the cycle.

Senile involution may be aggravated and hastened by many other causes of decay to which our flesh is heir; in such cases, however, senility is a morbid condition, not a function of age, and may be noted before the close of maturity and belongs to the department of pathology. Old age begins at fifty in women and at sixty in men. Some scientists subdivide it into three stages: that from sixty to seventy years of age, when the first signs of decay appear (*viridis senectus*); seventy to eighty, the phase of frailty (*grandaevi aetas*); and the period from eighty to the close of life, the phase of *longevity*, or *aetas decrepita*. These divisions are artificial, not being distinguished from one another by anatomical or functional characteristics: their appearance and expiration may be hastened or retarded by various external and internal conditions, such as climate, special kinds of work and nourishment, race, sex and hereditary tendencies.

The problem of human senility and of its ultimate consequence, death, has given food for thought to many, from the theologians and philosophers of ancient times to the most modern of biologists. They have all regarded it as the most interesting and important of life's problems. It will therefore be well to take a rapid survey of the views which have succeeded one another on the subject of old age and death, since these views afford us an idea of the general advance in scientific knowledge.

Greek philosophy regarded the process of senility as intimately connected with the gradual development of *innate heat*, by which they understood and symbolised the sum total of the virtual energies and hereditary tendencies accumulated in the germ. After the discovery of the circulation of the blood and lymph, the condition of the heart and blood-vessels came to be regarded as an essential factor in determining the different ages of life, old age and death included. After the earliest microscopical researches the *state of the fibre*, the gradual changes of the constitution of the organised elements of the tissues, were considered important for the determination of the ascending and descending phases of life. Finally, with the development of bacteriology and the chemistry of the secretions, the bacteria found in the intestines and the influence of the glands of internal secretion were considered the fundamental conditions of growing old.

Aristotle, in his works *De juventate et senectute* and *De*

spiratione, set up the theory that every organism from the very beginning of life contains the *innate heat*, the decrease and final disappearance of which are the causes of senility and death: "Generatio igitur est prima altricis animae communio cum calore, vita autem illius mansio. Juventus est accretio, quam prima refrigeratrix pars suscipit. Senectus eius ipsius partis diminutio. . . ." We find this doctrine, which, indeed, lasted until the days of scholasticism and even later, in the physiological system of Heraclitus, derived from Hippocrates and the followers of Aesculapius. Thus, for example, Anselm in his *Gerocomica sive de senum regimine* (Venetiis, 1606) speaks of old age as "esse viventis defectum ex debilitate calidi innati ob naturalem diminutionem humidi radicalis."

Cicero gave another interpretation of old age, comparing it to a disease: "*ipsa senectus est morbus.*" Although this doctrine is essentially erroneous, since old age is a special phase of life just as are childhood, youth, and maturity, it nevertheless assumed many different aspects in the course of time, forming the subject matter of many literary works, in which true *physiological senility* is constantly confounded with that studied by Charcot in our own day under the name of the *pathology of old age*. Amongst those who have contributed to this literature are Camerario (1684), Schraeder (1699), Glagau (1705), Hutter (1732), the last-named of whom proposed to prove "*quod senectus omnino morbus sit, et instar morbi in corpus agat.*" Other writers disagreed with this view and took up a more accurate and scientific position. If we regard man not as something complete and incapable of change during his life, and bear in mind that although his outward conditions may remain the same, he himself is constantly changing, and passes through certain spontaneous crises, such as puberty and the change of life, we cannot fail to see that old age is the last stage of the evolutionary process to which man is subject during his individual life, that it is the natural phase of an uninterrupted development based upon the internal complex constitution of the living substance, of which the germ or fertilised ovum is the first beginning.

This idea, which Verworn amongst modern writers has treated in his *Allgemeinen Physiologie*, is not entirely new.

Bacon puts the question well in his *Historia vitae et mortis* (1623), and points out that organic repairs are made only during youth, and so extensively during that period that they increase the substance of the body; but "*vergente aetate, inequalis admodum fit reparatio.*" It is worthy of note that he distinguishes clearly between those parts which can readily be repaired (the blood, flesh, and fat) and other tissues and organs *sicciores aut porosiores* (membranes, nerves, arteries, veins, bones, and cartilages) in which the process of repair is *difficilius et cum jactura*.

Wolff in a dissertation entitled *De senectutis natura* (1748), after stating that "sanissimus homo senescit," concludes that "oportet ut id in essentia hominis in genere fundatum sit," and proceeding to analyse the principal cause of old age, attributes it to the "resistentia fibrarum . . . magis magisque increscens," which, becoming more marked in the vascular system, leads to death from cardiac disorders.

Richter (1724), a disciple of Vater, influenced by the new study of the glandular organs, found the cause of old age in the influence of the secretions upon the exchange of material, which he regarded as bound up with the "imminuta reparatio absumpti." This view has been adopted in recent times by Lorand (1904), who sees in old age merely the action of the endocrine glands, which he thinks preside over and regulate the trophic processes of the organism. In premature senility he finds analogies with myxoedema.

Erasmus Dárwin agreed with the medical authorities of his day in the view set forth in his *Zoonomia*, that old age depends upon the "exhaustion of irritability." "It seems," he writes, "our bodies by long habit cease to obey the stimulus of the aliment which should support us. After we have acquired our height and solidity we make no more new parts, and the system obeys the irritations, sensations, volitions, and associations, with less and less energy, till the whole sinks into inaction."

Valli tried to find in chemical phenomena an explanation of the organic changes of old age, which he ascribed to the accumulation of calcium phosphate in the interior of the tissues, hardening and solidifying them and impeding or stopping their action. Hamelin, on the other hand, connects old age with the natural process of ossification which begins during foetal life and ends with death.

Other writers have limited the state of senile involution to a given tissue or organ, for instance to the respiratory system, with consequent imperfect formation of blood (Réveillé) or continuous production of connective tissue (Boy-Tessiers). Others again regard old age as resulting from a chronic intoxication (Brousse), or from progressive arteriosclerosis (Charcot). This last view merits special attention.

Arteriosclerosis is regarded by some not as a morbid process in the ordinary sense of the word but as a physiological process, one of the necessary heritages of human evolution, easily identified with the process of senility. They adduce various arguments in favour of this identity of arteriosclerosis and old age:

1. In old age the tissues of the organism are subject to gradual fibrous and sclerotic metamorphosis.

2. Senility is hastened by the same causes which induce morbid arteriosclerosis, and especially by excessive muscular work, grief, and the abuse of alcohol.

3. The phenomena of arterio-sclerosis hardly ever appear before adult age, and frequently seem to be the result of natural causes, since grave irregularities of function or habits are by no means always noticeable in old people attacked by it.

Cazalis's aphorism, "On a l'âge de ses artères," is based on the clinical observation that arterial changes exercise a powerful influence on the whole system. Boerhaave, who regarded the whole body as consisting of vessels and fibres, believed, as Haller points out, that senile decay and death are due to the hardening of the arteries, "ut cor eam resistentiam superare nequeat." Although it may be an exaggeration to ascribe—as does Demange—all the changes which take place in old age to this cause alone, its great importance in the acceleration of the other phenomena of senile decay cannot be denied.

Metschnikoff agrees that arterio-sclerosis is one of the main causes of senile decay; he however ascribes no physiological significance to it, but considers it to be invariably due to chronic intoxication, which may be caused by

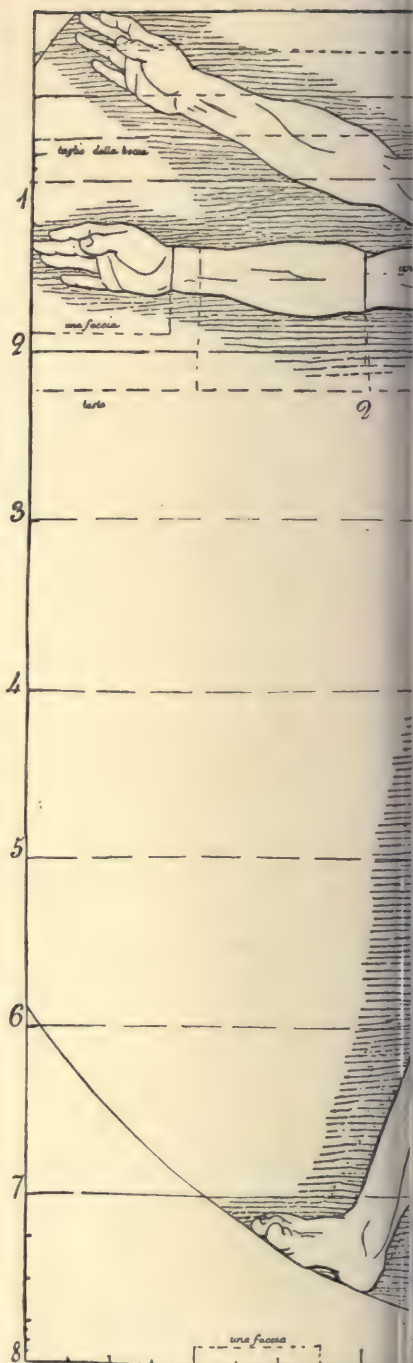
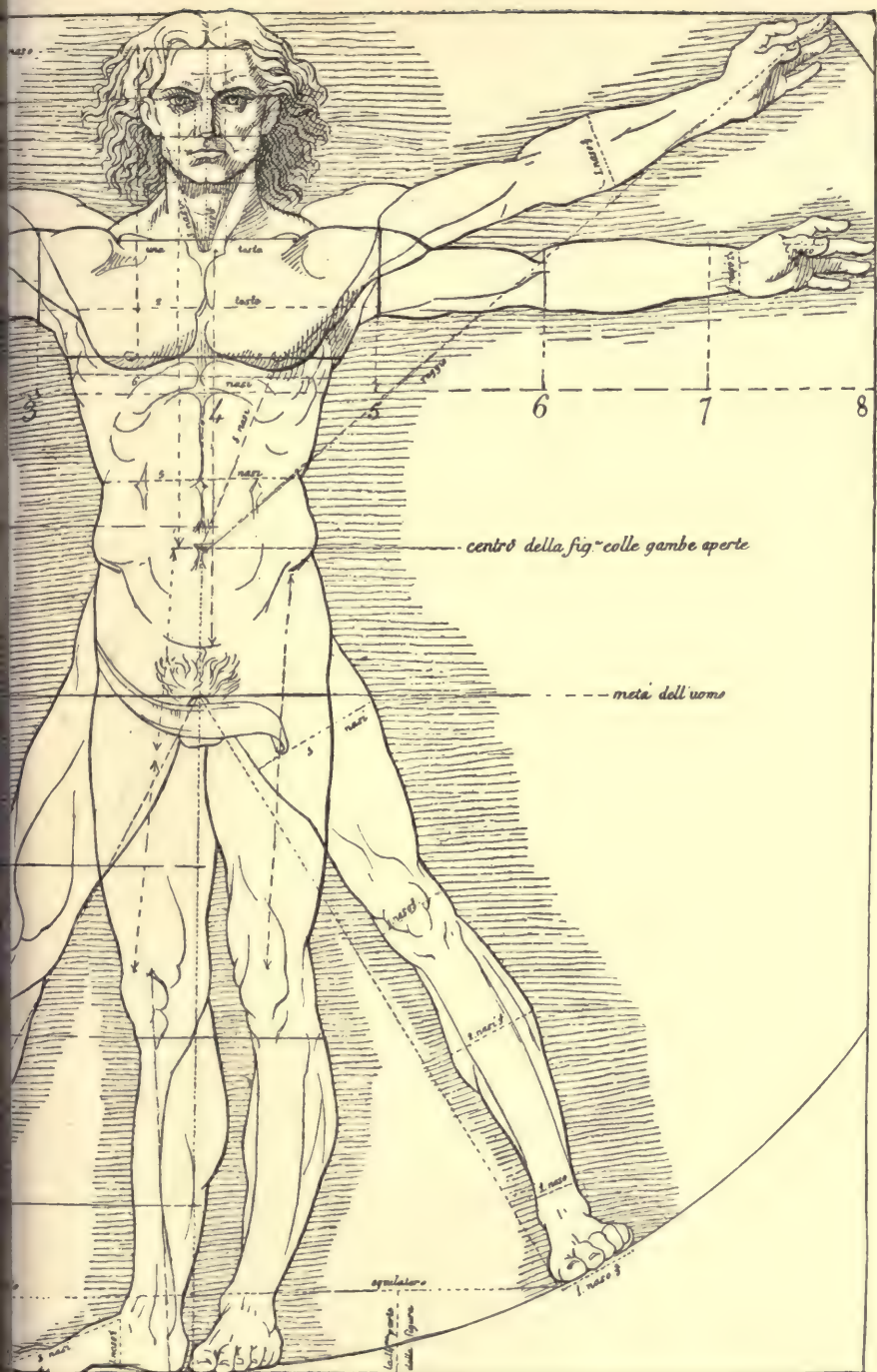


FIG. 122.—Reproduction of a drawing by Leonardo da Vinci in the Accademia di Belle Arti at Venice. (The general divisions are partly taken from Vitruvius.)

The height of the man of average stature is eight head lengths, as is seen in the drawing. The half of the body length is at the end of the pubis. If the arms be raised horizontally, the distance between the tips of the right and left middle fingers is equal to the entire height of the man. If the legs be stretched out and the arms raised to the level of the top of the head, as shown in the sketch, the navel becomes the centre of a circle which passes through the extremities of the outstretched limbs, and the space between the feet and the pubis forms an equilateral triangle.

From above the breast to the top of the head is a sixth of the whole figure. From the line of the nipples to the top of the head, from the nipple line to the pubis, from the pubis to below the knee, and from this point to the sole of the foot, are four equal spaces, each measuring two head lengths, or a quarter of the man; just as we have the same length from the tip of the middle finger to the end of the biceps at the widest point of the shoulders. From the elbow to the shoulder is one head or four nose lengths. From the centre of the eye to the navel and thence to the beginning of the knee-cap are spaces of equal length. (This explanation of the figure is by Leonardo.)



alcoholism, infection (syphilis), or toxic products developed by the bacteria found in the intestines. He lays stress upon the enormous number of bacteria which accumulate in the large intestine, since the remains of undigested food afford an excellent culture medium for microbes. Bacteria indeed form a large proportion of the faeces. The question whether the bacteria found in the intestines serve a useful purpose in the process of digestion is one which has given rise to much discussion and to many experiments. Metschnikoff regards them not merely as useless but as actually harmful. In support of this theory he adduces the fact that in diseases in which there is intestinal stasis the toxic products become diffused throughout the organism, as was proved by Ewald in the case of a patient suffering from an intestinal fistula; these toxic products suffice in the absence of any other cause to set up arteriosclerosis and hence senility. Metschnikoff made further experimental researches into old age in 1910, and showed that aortic atheroma, cirrhosis of the liver, and chronic interstitial nephritis may be induced in animals by small daily doses of paracresol continued for months at a time. Okhuba, and after him Dratchinsky (1912), obtained organic lesions like those found in the organs of old people by administering minute doses of indol to rabbits, guinea-pigs, and monkeys.

Ribbert, however, observed that this theory of intoxication rests entirely upon hypothetical grounds. The idea that it is possible for bacterial toxins to become reabsorbed in the normal healthy intestine under normal conditions of life amounts to the admission of the possibility of *physiological intoxication*, a contradiction in terms. Such poisonings do not take place, because under normal conditions all the more or less toxic products of metabolism which are developed in the organism are promptly eliminated by it.

Ribbert observes that the retrogressive changes of old age take place in all the organs and in the same typical order in each of them, resulting in the state of physiological senility. It is therefore arbitrary to assert that enterogenic toxins must act mainly on the vascular system, and that the changes in this system bring about all the other changes, even those in the brain, and are thus responsible for death from old age.

Metschnikoff is of the opinion that the most specialised and most active elements of the organism succumb to the action of those poisons, and the lower connective and supporting tissues grow at their expense. In order to explain this phenomenon of substitution which is identified with the process of growing old, he has recourse to the doctrine of *phagocytosis*. The macrophages in the circulation have no difficulty in coming into contact with every part of the organism, and normally do good defensive service by absorbing abnormal or extraneous elements,

and the refuse of the tissues; it not seldom happens, however, that under the stimulus of poisons present in the blood (such as the toxins of infectious diseases, alcohol, the poisons of intestinal putrefaction, especially of protein substances, endogenous and exogenous poisons generally), they go beyond their proper sphere of activity, destroying and absorbing the higher cells of the organism, for which nothing but connective tissue can be substituted, hence the *sclerosis* of the organs of old people. Metschnikoff believes that his microscopic researches have enabled him to discover the macrophages which surround the ganglion cells and those of the kidneys, liver, bones, and contractile substance of the muscles, etc. The mechanism of senile atrophy therefore is just like that of atrophy due to the action of bacteria or toxins, hence the doctrine of the pathological genesis of old age.

But if we look at it more closely, this doctrine is an abuse of the theory of *phagocytosis*. Even if it be granted that the macrophages work the havoc in the different elements which they are said to do, and hasten their dissolution, this fact would be merely a *secondary phenomenon*, and would shed no light on the essential fact of senility. Further, many histologists and neuropathologists refuse to admit the discoveries and microscopic figures with which Metschnikoff supports his theory; Cerletti (1903) bluntly terms them errors of observation. He examined a large number of senile brains belonging to persons who had died at over 90 years of age with pronounced atrophy, and found no sign of special phagocytic activity in the ganglion cells. On the other hand, he found the conditions discovered by Metschnikoff in the brains of young people which showed no sign of atrophy. The supposed macrophages are according to him merely glia cells, which are found also under normal conditions near the ganglion cells (*satellite cells*, the *Trabantzellen* of German scientists). Von Hansemann (1907), Saigo, and others came to the same conclusion and noticed the same appearance in individuals of all ages.

Salimbeni and Gery, who belong to Metschnikoff's school, have recently made an accurate anatomical and histological study of a senile organism; they found in the various sclerosed tissues mononuclear and macrophagic infiltration, cellular degenerations in the liver and pancreas, hypoplasia of the adenoid organs, and calcification of the blood-vessels, the choroid plexuses, and the medulla. The hypophysis and the thyroid gland showed signs of decreased functional activity, and the supra-renal capsule those of over-activity. The most important and the most widespread of all these lesions is sclerosis, which leaves no organ unspared and is due to mononuclear and macrophagic infiltration.

These various forms of deterioration cannot all be explained by auto-intoxication arising in the intestines, for it fails to account for the fact that certain organs, especially the genital

organs of women, undergo a process of involution at a certain period, quite regardless of the kind of life led by the individual. The various cellular degenerations in the glands of internal secretion cannot all be due to one and the same cause; moreover, a fundamental fact in the process of growing old—the gradual slackening and final cessation of cellular reproduction—is still shrouded in mystery.

We have paused to consider Metschnikoff's teaching, because this writer has drawn from it practical conclusions which have been received with great interest by the laity. The ancient maxim of Cicero that we must struggle against old age as we would against infirmity has been adopted once more, and the proposal has been made to check the development of bacteria in the intestines, not merely by means of moderation in food, but also by the habitual use of various forms of fermented milk (the *kephir* of the Caucasus, the *koumis* of Russia, the *yoghurt* of Bulgaria, the *gioddu* of Sardinia), and by the administration of cultures of bacteria producing lactic acid, so as to check or prevent intestinal putrefaction.

Whatever may be the practical value of his hygienic precepts (one of which, *moderation in food*, is excellent and supported by the latest scientific researches), it is obviously both useless and erroneous to expect that they will enable us to avoid the effects of old age, which is, as we have already said, not a morbid process due to intoxication, but an inevitable physiological process of involution.

VII. In order to understand the causes of natural death, we must have a scientific idea of the *physical basis* of old age which gradually prepares the way for it. The changes which age brings about in our organism consist of *atrophic processes* affecting all our organs to a greater or less extent, no matter whether they have been subject during life to the influence of disease of either a transitory or chronic kind. The constancy with which atrophy of all the organs is noted in old age is regarded by J. Cohnheim as a proof that it is a physiological involution (Preyer's *cata-plastic phase*). C. S. Minot also, in his studies on growth, comes to the same conclusion.

The entire organism of the aged presents certain characteristics and physical features which have inspired the art of the greatest painters and the poetical realism of Baudelaire. The approach of old age is almost always heralded by a falling off in weight, accompanied by more or less pronounced anaemia (*senile anaemia*). The blood becomes poorer in erythrocytes and haemoglobin (Solokoff); the proportion between white and red globules may exceed 1 : 650; the resistance of the blood corpuscles diminishes especially after the seventieth year (Obici). Excessive stoutness is seldom seen in old people (Bichat).

In addition to the commencing general atrophy, we find fatty degeneration, pigmentary infiltration, calcareous incrustation and infiltration (*calcification*) and ossification. These processes are the main general features of old age; they may spare certain organs, and yet be extremely advanced in others.

The atrophy of the skeleton is above all remarkable. The bones are markedly affected by senile atrophy; they become smaller in all dimensions; the compact bones become thinner, the spongy ones more rarefied, whilst they all become very brittle (*fragilitas vitrea*), especially those of the lower limbs, owing to the changes in the nutritive vessels and the removal of calcareous salts (Nélaton and Sappey). The red marrow disappears and the fatty marrow diminishes and tends to become gelatinous.

Owing to this change in his bones, man becomes bent under the burden of years, he stoops and grows thinner; his head becomes smaller owing to a retrogressive process in the skull which has been thoroughly studied by Sauvage (1869). The face undergoes changes which are still more marked, the decay or loss of the teeth diminishes the height of the jaw and makes it project more, thus shortening the distance between the nose and the chin. These and other changes in the bones show that the characteristics of senile physiognomy are due to the skeleton, and not merely to alterations in the softer parts.

The connective tissue in the aged diminishes less than do the more active tissues. The heart, the blood-vessels, the liver, the kidneys, and the spleen of old people are relatively richer in connective tissue than in the normal conditions of youth. The connective tissue of the aged is however more tenacious, sometimes thicker; it is more homogeneous in the skin, and of less functional utility (Ribbert).

The muscles become smaller and paler with the disappearance of the transverse striation and the sarcolemma; the perimysium, on the other hand, is increased, and we sometimes find fatty infiltration. Faradic excitability in the lower limbs is always less than in the upper ones (Ghelfi). *Senile tremor* (Sauvage) results from neuro-muscular weakness and from the diminished frequency of the contractions in the performance of voluntary acts (*tremitus a debilitate*). It is compatible with perfect health. It usually begins with the head, more rarely with the hands, and seldom extends to the lower limbs. It is continuous, slow (four to five times per second), oscillatory, rhythmic, and involuntary (Pieraccini).

The joints of the aged are often weak, and even when they do not look red or swollen, crepitation is often noticeable, especially in the knee-joints. The condition of the muscles and joints, together with the retrogressive cerebral and spinal changes, is the cause of the awkward, slow, and frequently limited movements

of the aged and of the *vacillatio senilis* which resembles that caused by cerebellar disorder.

The heart of the aged does not often become smaller and the sounds want clearness but are sometimes sharp. Damage speaks of a senile cardiac hypertrophy, caused by arteriosclerosis of the aorta and of the other arteries. Ribbert also noted hypertrophy of the myocardium in individuals dying in extreme old age, and in one case of an old man suffering from recent interstitial nephritis.

The whole arterial system loses its elasticity in old age, consequently the circulation is less active and the pulse slower and less frequent. This diminished elasticity and contractility (Ribbert) is a regular feature of senility and comprises the whole circulatory system (arteries, capillaries, veins, and heart).

In this connection there arises the important question whether arteriosclerosis is an essential characteristic of old age or merely one which occurs very frequently and must be regarded as a complication of the strictly physiological senile state. Huchard and Schobert have asserted that arteriosclerosis is a constant occurrence in old age. The prevalent tendency of the present day, which is the outcome of the most recent and thorough anatomical and clinical research, such as that of Ribbert, Thomas, Hampeln, and others, is to distinguish between arteriosclerosis of a pathological type and that of physiological senility. As we have already seen, however, the process of atheroma in both arteries and veins (*phlebosclerosis*) which may lead to real calcification is extremely common in old people. The atheromatous process attacks the most important blood-vessels (aorta) and the secondary ones alike. In advanced old age we always find tortuosity and hardening of the temporal vessels, and the same symptoms frequently occur in the arteries of the lower limbs. The crural arteries and veins frequently turn into stiff calcified cords (Birch-Hirschfeld, Sach, Ghelfi), thus accounting for many disturbances in the gait of old people and attacks of *intermittent lameness*. It is of course impossible here to draw a strict line of demarcation between physiology and pathology, since the retrogressive physiological alterations induce inflammatory reactions, which complicate the syndrome. We can, however, adopt Kaufmann's view that in chronic senile arteriosclerosis the processes of degeneration predominate.

When we come to the general involution of the organism of the aged, the liver presents the most points of interest; the *brown atrophy*, which reduces its volume by about one half, depends upon the shrinking of the hepatic cells, especially of those in the centre of the acinus. These cells also contain a larger number of yellowish-brown pigmented granules than those of the periphery of the acinus.

The kidneys show a form of atrophy throughout the parenchyma. The colour turns to a reddish brown in most cases, and the surface becomes wrinkled and granular. The atrophy is due to the shrinkage of both the winding and the straight tubules and of the epithelial cells which become shorter with smaller nuclei. The tubules may grow thinner and disappear and their glomeruli be obliterated.

There has been observed in old people an increase in the size of the supra-renal capsules which become mammillated and convoluted in appearance (Sabrazès and Husnot, 1906).

The question of the hypertrophy of the prostate gland, which is extremely frequent in old people (occurring, according to Thompson, in 56 per cent of those over 60 years of age), is under discussion, some scientists regarding it as of solely pathological character.

Symptoms of atrophy are seen also in the gastro-enteric organs; the mucous membrane becomes thinner, the glands smaller, and the muscular coats thinner. The cells of the various sections contain a light yellowish-brown pigment.

The thorax of the old differs from that of the young in that it is less mobile and elastic. The lungs of the aged, which were first studied by Magendie, frequently show senile emphysema as well as a certain degree of atrophy.

The majority of the changes in the peripheral nerves described as characteristic of senility are in all probability connected with morbid conditions, and especially with chronic intoxications.

As a rule, the muscular sense and the various forms of cutaneous sensibility appear to be normal, with the exception of the sense of pain, which seems to be somewhat dulled, especially in the upper limbs. The nerves are sometimes painful when compressed, but preserve their normal electric excitability and do not show the reaction of degeneration.

Numerous changes take place in the organs of sense, more particularly in the eyes and ears. Angelucci considers that the chromatic sense in the old is also liable to change, so that the aged fail to distinguish between white and light yellow, and between blue and green.

The researches necessary to determine the changes in the senses of touch and smell in old age have not as yet been made.

The spinal cord of old people shows amyloid bodies to be specially numerous; the changes undergone by the grey matter resemble those in the grey matter of the brain; in the white matter we find atrophy of the medullary sheaths, in consequence of which the whole of the cord shrinks, whilst the outer layer of connective tissue becomes thicker. It is not, however, possible to say for certain whether certain (sensori-motor) systems are

more liable to be affected than others. The spinal cord of the aged often shows marked fibrous sclerosis of the blood-vessels.

Most writers consider the integrity of the cerebellum in old age as being in obvious contrast to the atrophy found in other parts of the encephalon; this integrity of the cerebellum is not however absolute, as was shown by Anglade and Calmetta in 1907. The senile changes in the cerebellum are not marked

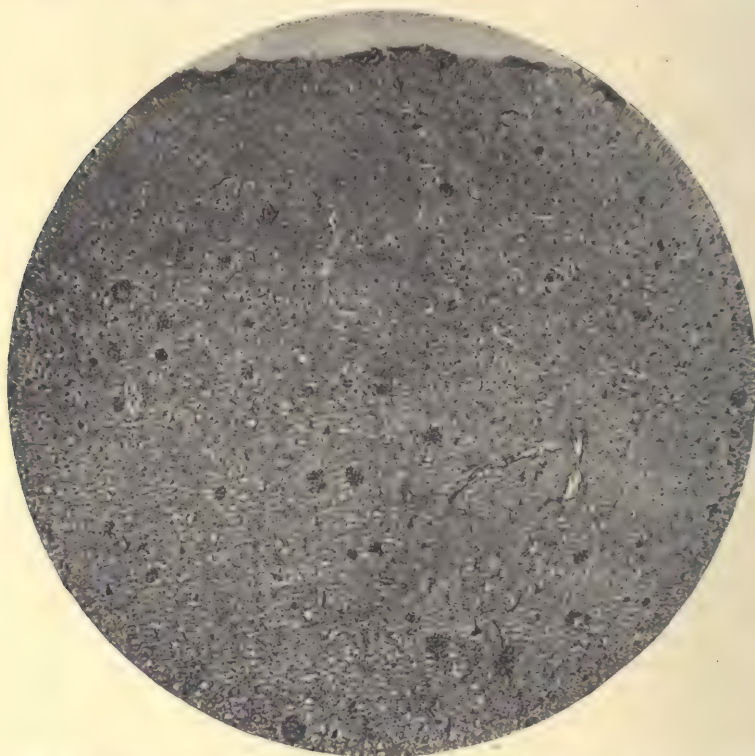


FIG. 123.—Cerebral cortex of an old man aged 102 years, treated according to Bielschowsky's method; low magnification. The whole of the grey matter is sprinkled with miliary necroses (senile patches) of Redlich-Fischer. (Micro-photograph by Dr. Perusini.)

by atrophy *in toto*, but by partial atrophy of a very circumscribed order resulting in the establishment of the perivascular foci known as the lacunae of disintegration, which occur most frequently in the limiting sulci of the cerebellar lamellae.

The changes which take place in the brain of the aged are of the greatest importance to the subject of natural senility. Pathological anatomy has recently succeeded in finding one change in the brain which is peculiar to senile involution, whereas hitherto nothing really specific in this direction has been

found in any other organ. None of the alterations which we have enumerated can be regarded as pathologically indicative of senility: many of them are directly or indirectly connected with arteriosclerosis, a disease which, whilst very common in old people, is not exclusively a sign of senile physiological involution. Certain other alterations are probably directly connected with

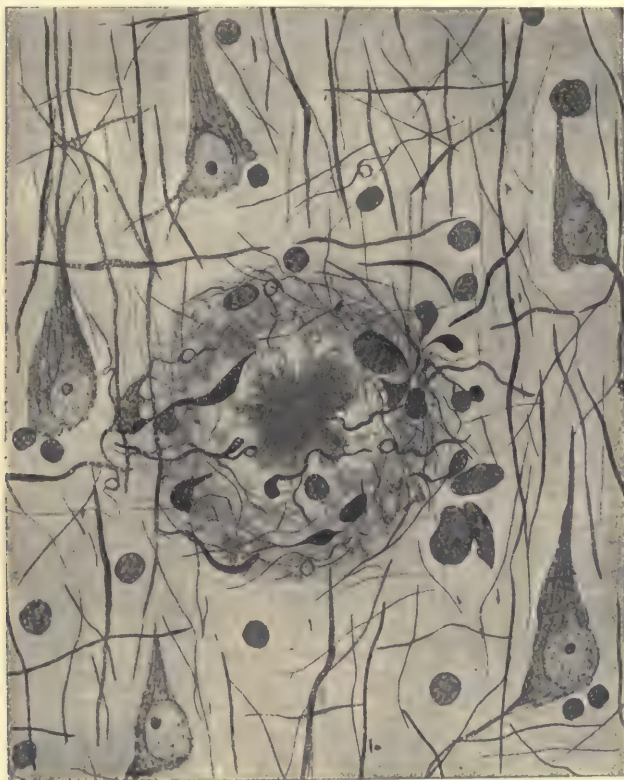


FIG. 124.—Miliary necrosis (senile patch) of the cerebral cortex of an old man, aged 102 years, highly magnified, treated according to Bielschowsky's method. In the centre a degenerate mass is seen, surrounded by a ring of thickened material. (From a preparation by Dr. Perusini.)

senile involution, especially the processes of simple atrophy of the histological elements, but even this class of change is not in itself a specific proof of senility.

The recent researches of Alzheimer, Simchowicz, Fischer, and more particularly the investigators of the Roman school, Cerletti, Perusini, and Bonfiglio, have pointed out a number of alterations characteristic of senile involution. Amongst these changes we find several which may be regarded as indicative of senility

exclusively, since they never occur except in the brain of persons suffering from physiological decrepitude or in whom abnormally early decrepitude has caused a particular form of disease called senile dementia. Of these changes the first to be mentioned are Redlich-Fischer's miliary necroses or senile spots, extremely small areas of destruction scattered sometimes in very large numbers all over the cerebral cortex (Figs. 123, 124). The majority of the remaining nerve cells are found to be in a more or less advanced state of fatty degeneration (Figs. 126 *a, b, c*, 125 *b*), and in these cells a special form of change is often noticed in the neuro-fibrils, which are wound round and round in bundles as in a ball of thread. Many cells besides succumb to simple atrophy, advanced rarefaction of the spindles of Nissl (Fig. 125 *c*) and to sclerosis (Fig. 125 *d*). The nerve fibres probably diminish in number; the radiating and transverse fibres appear to be rarefied in the white and grey matter of the convolutions. The atrophy of the medullary sheaths shows us why the atrophy of the white substance seems greater than that of the grey matter. We also find in the senile brain sclerotic retraction of the neuroglia, in which accumulations of fatty granules are also found.

Cerletti has recently described loops, knots, and extremely complicated tangles in the blood-vessels of the grey matter, formed by one or more small arteries, pre-capillaries, and veins (Fig. 127). These strange formations, which are constantly found in the senile brain, are due partly to atrophy of the tissue traversed by the vessels, partly to their gradual distension owing to the decreasing resistance offered by their walls to internal pressure. Since many vessels are not affected by the atrophic processes which attack the nervous parenchyma, they are forced to adapt themselves to a course much shorter than their length; they therefore pursue a tortuous path which in its later stages causes the formation of loops and extremely complicated figures (Fig. 127 *b*).

The presence of innumerable miliary necroses, the various trophic and degenerative changes in the cells and nerve fibres, the sclerotic retraction of the neuroglia, and the alterations in the parenchyma consequent on the disturbances of nutrition caused by the winding course of the blood-vessels result in serious atrophy of the brain as a whole. It shrinks, and its absolute weight diminishes (1295-1095 grms. according to Verga); the convolutions become thinner and the sulci wider. This atrophy is prevalent in the frontal lobes, the corpus callosum, the corona radiata, and the grey nuclei of the base; it results in an *ex vacuo* dilatation of the ventricular cavities. These changes are not equally marked and constant in old people of the same age, but take place very early in some and late in others. Hansemann found that the brains of Mommsen and Bunsen, who died at 86 and

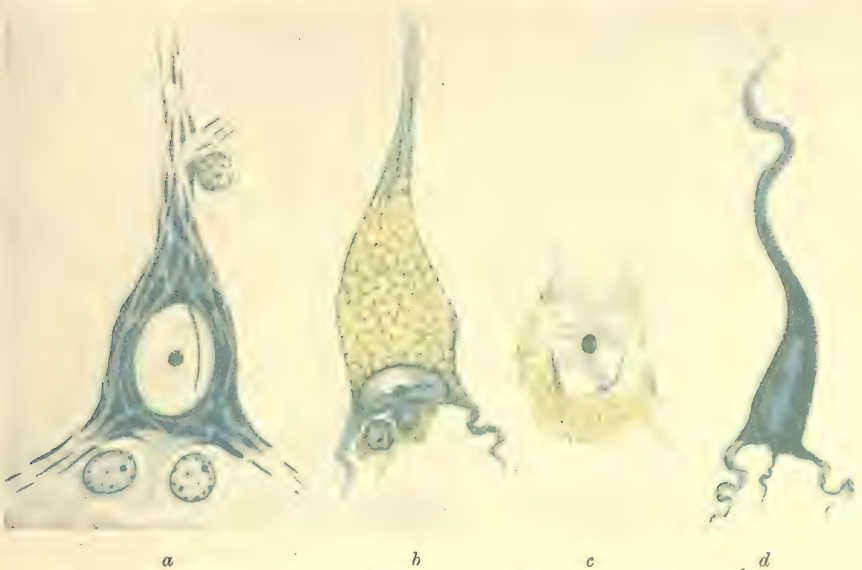


FIG. 125.—(a) Normal nerve cell (large, pyramidal) of the cerebral cortex of a youth of sixteen, treated according to Nissl's method; *b, c, d*, nerve cells (large, pyramidal) from the cerebral cortex of old people, treated according to Nissl's method; *b*, pigmentary degeneration (fatty) of the whole cytoplasm, with displacement and dissolution of the nucleus (the two neuroglia cells are also full of fatty granules); *c*, dissolution of the whole cell (last stage of fatty degeneration ?); *d*, sclerosis. (From preparations by Cerletti.)

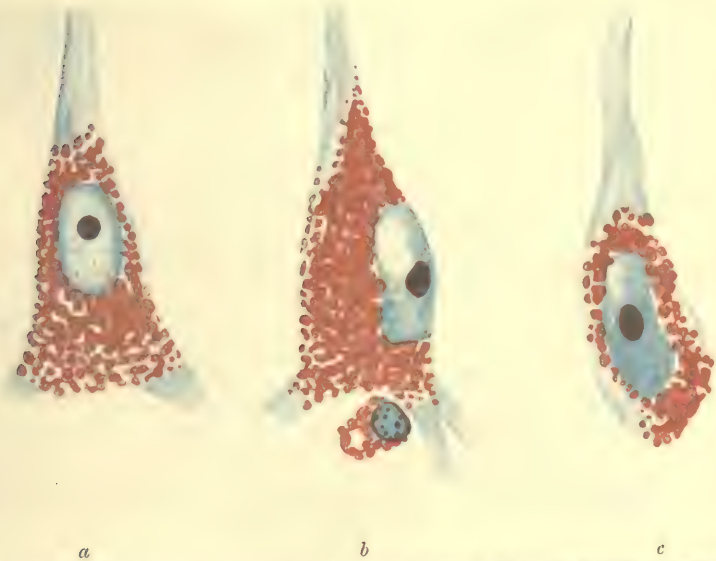


FIG. 126.—Nerve cells (large, pyramidal) of the cerebral cortex of old people treated according to the method of Daddi and Herxheimer for fatty substances. The cellular body is more or less full of fatty globules. In *b* the neuroglia cell is also charged with fatty globules. (From preparations by Cerletti.)

88 years of age respectively, showed plain signs of atrophy which were not present in the brain of Menzel, who was 89 when he died.

In connection with the lengthening, twisting, entanglement, and disorder of the blood-vessels, we are confronted once more with the vexed question whether these changes are signs of pathological senility or are in part indicative of the arteriosclerosis which so frequently attacks the old. A series of clinical and

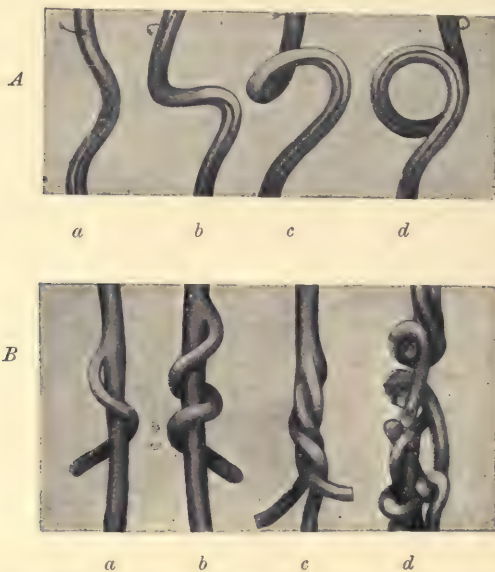


FIG. 127.—A, Semi-schematic figures showing the mechanism by which the cerebral vessels of old people gradually change from a simple spiral winding to complete loops, *d*. This process is due to the fact that the vessels are forced to adapt themselves to a space considerably shorter than their own length, in consequence of the atrophy of the tissue and the lengthening of the vessels themselves. The black lines and the arrows indicate the tortuous movement on the longitudinal axis, a movement which corresponds to a complete revolution of the vessel on its own axis for each loop. B, Semi-schematic figure showing the results of the tortuous movement of the vessels on their longitudinal axis. (Cerletti.) *a*, *b*, collateral vessel twisted round the parent stem; *c*, three terminal branches intertwined; *d*, extraordinarily complicated tangle of vessels.

anatomical investigations of a convincing and decisive order have shown in arteriosclerotic brains and in those of arteriosclerotic lunatics the presence of patches of damaged tissue, usually of the type of *perivascular gliosis* (Alzheimer), in addition to the usual centres of haemorrhage and softening; these patches alternate with and are sharply defined from more or less extensive tracts of cerebral substance which are relatively unimpaired. In pure cerebral arteriosclerosis miliary necrosis is absent. In the physiologically senile brain, on the other hand, the changes are *diffuse* and affect the whole cortex, and more especially the nerve

cells (fatty degeneration, alterations in the coiling of the neuro-fibrils, miliary necrosis, etc., as shown in Figs. 125, 126). Although *senile dementia* is a disease *sui generis*, it is nevertheless in closer affinity with *simple* physiological *senility* than with the *arteriosclerotic dementia* which exists independently of senility.

From all these retrogressive changes in the different organs and systems which we have described we may form an idea of the functional modifications in the senile organism and can readily understand its susceptibility to the many forms of disease and discomfort which trouble old age. "*Multa senem circumveniunt incommoda*," writes Horace, and few indeed are the old people who are fortunate enough to attain to the average physiological length of life, which should be about a hundred years. Cases of longevity of nearly 150 years have indeed been known (Hermann), as well as one case of 160, another of 163, another of 169, and two of persons who lived to be nearly 180 (Burdach).

VIII. The various forms of degeneration in the brain which we have described may be fairly well deduced from the large number of changes in the intelligence, the mental activity, the emotions, the character, and in fact in the whole psychic personality of the majority of men as they advance in years. The first and commonest changes of a psychical order noted in old people are those in their habits, together with modifications in their character which make them diffident, credulous, susceptible, discontented with everything, *laudatores temporis acti*. Cicero said that one of the advantages of old age was its exemption from the passions, but this phenomenon—if we consider it closely—arises from the fact that egotism, the desire for a quiet life, and a lack of interest in the misfortunes or unhappiness of their neighbours are predominant in the old. The old person is the survivor of a vanished generation, and is lonely and forsaken in a new world in which he is no longer strong enough to take any interest. As a rule he does little but say how old he is, taking any one he comes across into his confidence that he may be encouraged to hope for long life. The psychic degeneration of the old is shown by the gradual dissolution of the mental structure, the temporary checks in the psychic current, the frequent failures of memory, the weakening of the will and the imagination, and the uncertainty in judgment.

Whilst in the case of individuals whose tendencies are good and who have led a regular life and escaped serious illnesses these involutionary phenomena of the personality make their appearance very late and are scarcely noticeable, in persons who have inherited bad tendencies or have suffered from diseases specially affecting the circulation these psychic changes are not confined to the limits we have described, but are exaggerated,

thus bringing about early and serious degeneration in both physical strength and psychic powers sufficient to constitute a genuine form of progressive mental weakness, and of *senile dementia*, which, accompanied by phenomena of a paralytic type, increases till it ends in death.

The first symptoms of this morbid old age affect the character; they are diffidence, avarice, change in the moral and altruistic sentiments, accompanied by transitory excitement of the sexual instinct. The flow of thought becomes incoherent, feeble, and confused; the realm of consciousness narrows; the remembrance of recent facts is dim and that of more distant events vivid. Such old people become tiresome and uninteresting; they care about nothing but their own affairs, which they are quite incapable of managing; they are full of childish fancies and are extremely sensitive and vain; they are apt to suffer from attacks of giddiness, drowsiness, or unconquerable insomnia. Their mentality gradually reaches the last stage of decay, all active energy comes to an end, and their ways, behaviour, and expression become infantile. They laugh or cry without reason, tear or soil their clothes, take no notice of micturition, and eat untidily. Based upon this mental weakness there are often periods of disorder, with incoherent ravings about persecution, maniacal agitation, and hypochondriacal ideas. In these states of depression (described by Gaupp) the dominant features are great psychical and ethical decadence and incoherency of ideas, or a condition of anxious melancholy with delusions of poverty and want, disgust with life, and attempts at suicide. These phenomena are often interrupted by attacks of an apoplectic or epileptic nature, states of aphasia with hemiplegia, and facial, hypoglossal, or other paralysis.

IX. The concept of *death* is closely bound up with that of *life*. Their connection is only too evident: "La vie est la contraire de la mort," wrote the French encyclopaedists; "la vie est l'ensemble des fonctions qui résistent à la mort," said Bichat; "la vie est création, la mort est destruction organique," said Cl. Bernard. We call the processes of creation and evolution *anabolic*, those of destruction and involution *catabolic* (see Vol. I., Chapters I. and II.).

During the *anaplastic phase* of life, when the organism is growing, developing, and carrying out its functions with great activity, the anabolic processes predominate; during the *cataplastic phase*, when the organism is decaying, growing old, and dying, the catabolic processes have the pre-eminence.

All we have said about the bodily basis of old age and its physical and psychic phenomena affords clear proof of this statement. Death inevitably takes place when, owing to organic destruction (or, to put it better, to the prevalence of catabolic processes), the vital conditions essential to the functions of the organism are no longer present. It is never immediate; there

is no exact boundary separating life from death, but there are intermediate states between them. Schultz and Virchow applied the terms *necrobiotic* and *necrotic* to the processes through which the vital elements gradually pass from life to death, according to whether the element which perishes is disintegrated or preserves its form.

In the single cells or elementary constituents of the tissues we see in various forms the changes leading to death. The study of these changes (atrophy, degeneration, etc.) pertains to the pathological anatomist and we have already given a brief description thereof. From our physiological point of view we may remark that although much research work has been done bearing on this point, it is not possible to fix the exact moment of the death of single tissues; it is generally caused by delicate and gradual changes of a morphological, molecular, and chemical order, which for the most part elude direct analysis. Only in the case of the contractile tissues does rigor mortis afford us a clear fixed point with which the first moment of their death, or at all events the last act of their life, can be made to coincide (M. Schiff).

The different tissues from birth to the end of life are subject to retrogressive changes varying both in degree and rapidity. Owing to this fact we find in the cataplastic phase an ever-increasing lack of functional harmony in the organism as a whole, which when it reaches a certain degree of intensity becomes incompatible with life and inevitably leads to death. The immediate cause of death is *always intrinsic to the organism as a whole*, even when brought about by some external agency, but is *extrinsic to the elements* of a large number of the tissues, being caused by functional failure of the tissues and organs most essential to life, which have undergone more radical changes and upon which the life of the other tissues depends. This explains why death does not take place at the same time in all parts of the organism, but spreads from the higher tissues, which exercise more important and controlling functions, to the less important tissues the functions of which are of a subordinate and executive character. The length of the life of the cellular elements from which the higher organisms arise varies considerably. There are some cells in the tissues which disappear and are renewed, thus securing the functional continuity of the various organs and systems. The corpuscles of the blood are constantly perishing and being regenerated; the cells of the epithelium of both internal and external surfaces are continually degenerating, atrophying, and becoming detached, and as continually being replaced by younger ones. On the other hand, there are cells which have but a limited power of regeneration and corresponding to this a very much longer life.

B. Morpurgo (1898) showed that in the case of the functional growth of the voluntary muscles the increase in size is due to

hypertrophy of the pre-existing fibres, not to *hyperplasia* or multiplication of their number; it depends not on an increase in the number or volume of the primitive fibrils, but simply on an increase of the sarcoplasm. He was never successful in finding multiplication of the muscular nuclei. We remarked upon essentially the same fact in the preceding chapter with reference to the muscular fibres of the uterus during pregnancy (Chapter VI.). They are stable elements which last throughout life, becoming hypertrophied or atrophied either as the result of their increased or diminished functional activity or age.

Ribbert thinks that reproduction through mitosis ceases in many cells when the anaplastic phase—the period of growth of the organism as a whole—is over. Rabl considers that histological research has proved that the ganglion cells of the nervous system cease multiplying at a very early age, and remain unchanged and without renewal throughout life. I find this morphological fact confirmed by a phenomenon of a psychical nature: the events of early childhood are clearly and vividly remembered up to extreme old age, whereas those which are much more recent readily escape the mind. The grey matter of a child's brain is like a soft phonographic plate on which waves of sound leave deep furrows which time is powerless to efface; while that of the old is like a similar plate hardened by time and almost incapable of receiving a durable impression of the sounds which fall upon it. Yet it is the same grey matter, composed of the same cells which were formed in earliest childhood and still live in old age, enriched by the choicest fruits of experience and the deep marks of the past life, latent in the dimness of the sub-conscious, and more or less easily summoned into the light of the conscious.

It is obvious that this longevity of many histological elements, associated with their incapacity to multiply and rejuvenate by division, is the determining cause of their growing old and of the gradual decay which inevitably leads to their death and to that of the organism of which they form part, when their function is a regulating and dominant one, indispensable to the life of the social aggregate represented by the whole organism.

It is well known that the cells of the embryo and of young persons are as a rule more tenacious of life and possessed of a greater nutritive and germinative capacity than are those of the old. Even in old people, however, many cells are capable of reproduction; were this not the case, all processes of repair would be impossible in old people and even the slightest surgical operation would be undesirable. We are therefore forced to conclude that death, whether from disease or from natural causes, takes place when the central regulating and dominant organs, on which the life of the whole organism depends, cease to act owing either to morbid changes or to old age.

Francis Bacon (1623) was one of the first to treat scientifically the problem of *natural death*, that "quae fit per resolutionem ac atrophiam senilem." After dwelling upon the conditions essential to life according to the knowledge of his day, which had not advanced much since the time of Galen, he examines the *atriola mortis* or "portals of death," and describes the phenomena preceding, accompanying, and following the death of man. "Duo sunt magni praecursores mortis," he writes; "alter a capite, alter a corde missus."

Blühdorn (1715), speaking of the origin of death *ex aetatis vitiis*, attributes it to the circulation: "Hanc itaque in plenaria cordis motus et sanguinis circuli destructione, optima ratione, ponendam esse censendum est."

Others who have contributed to give us more exact knowledge of the *atriola mortis* are Harvey (1668), Littré (1706), Scheuckzer (1723), and Morgagni (1761), whose anatomical records of long-lived individuals undoubtedly opened the way to Bichat's *Recherches physiologiques sur la vie et la mort*, with its clear setting forth of the brilliant hypothesis of the *tripod of life*, represented by the brain, the heart, and the lungs. "L'action de l'un de ces trois organes est essentiellement nécessaire à celle des deux autres. . . . Les physiologistes ont connu de tout temps l'importance de ce triple foyer . . . tout espèce de mort commence par l'interruption de la circulation, de la respiration ou de l'action du cerveau. L'une de ces trois fonctions cesse d'abord, toutes les autres finissent ensuite successivement; en sort que pour exposer avec précision les phénomènes de ces genres de morts, il faut les considérer sous ces trois rapports essentiels."

Bichat admits that natural death is rare, and that with functional senile decay "termine presque entièrement la *vie animale*, longtemps avant que l'*organique* ne finisse."

Bichat's brilliant theories have been left almost unassailed by the great strides made by physiology and pathology; but his estimate of the importance of the three main centres of life and their order of precedence in the end of bodily life has been revised.

Nothnagel states that in the majority of cases of chronic or acute disease death is due to the heart. In a treatise on the signs of death Bouchut (1849) had already adduced as proof positive of definite death the cessation of the cardiac sounds as verified by means of auscultation all over the region of the heart. We know, moreover, that even cases of serious injury to the brain or lungs do not end fatally unless the heart gives out: the *ultimum moriens*, the true *atrium mortis*, is thus always the heart.

We must, however, have a clear understanding of the meaning of this expression, which only indicates the undeniable fact that of the three main centres of life the heart has the greatest power of resistance and therefore ceases to act last. When we endeavour

to indicate accurately the *internal condition determining death*, the problem must be stated very differently: granted that each of the three centres of life mentioned by Bichat is indispensable to the life of the whole organism we must ask: Which of them has the least power of resistance, *i.e.* which is the *primum moriens*?

The reply to this question may be based upon the study of the more, or less prolonged survival of the various organs when severed from the body of the animal, a subject which we have already had occasion to describe and discuss in different chapters of this treatise. We know that the kidneys, intestines, liver, and smooth and striated muscles are capable of surviving for a considerable time when separated from the animal, especially if subjected to artificial circulation. With respect to the heart, it will suffice to call to mind the surprising results of the experiments of Kuliabko and the younger Hering, who succeeded in reviving activity in the heart of both man and animals many hours or even three or four days after death. With reference to the nervous centres (which undoubtedly represent the dominant force in the life of the higher organisms), we know, on the contrary, that they offer less resistance than all the other tissues when the external conditions necessary for life are changed, and more especially when they are deprived of oxygen. The experiment made by Pflüger on the frog, to which we referred in Vol. I., Chapter III., is really surprising in its simplicity considering the importance of the results. These showed: (*a*) that the heart after the frog had been absolutely deprived of oxygen for twenty hours could still be revived by repeated insufflations of air; (*b*) that the muscles of the skeleton could be brought back to life after two hours had elapsed; (*c*) that still later the action of the spinal reflexes could be renewed, that is, the vitality of the nerve cells of the spinal cord could be restored; (*d*) that still later spontaneous respiration can be induced, that is, automatic activity of the cells of the bulb; (*e*) that the voluntary movements, *i.e.* the function of the cells of the higher centres of the brain, cannot be revived. Hence the brain is the part of the nervous system which is least capable of withstanding the deprivation of oxygen. This experimental fact leads us to the conclusion that the *primum moriens*, the internal condition causing death (whether as the result of old age, disease, or external injuries) is invariably the brain, the supreme ruler to which all the functions of the life of man and the higher animals are directly or indirectly subject.

The result of Ribbert's recent work, *Der Tod aus Altersschwäche* (1908), absolutely bears out this conclusion. In support of his thesis he adduces the arguments which may be inferred from the organic decay noticed in the old, the frequent drowsiness, the gradual weakening of the senses, in fact the whole range of phe of the senile mind which we have just described;

these lead logically to the conclusion that the fatal arrest of the cerebral functions must precede that of the cardiac functions, with which life finally ends. The brain, the culminating point of animal life, is the *primum moriens*; the heart, the central organ of vegetative life, is the *ultimum moriens*.

X. We have already pointed out that Metschnikoff, in his doctrine of pathological senility, regards natural death as a great rarity, as potential rather than actual. Should the prophylaxy suggested by him be successful and the presumed morbid state of old age thereby be prevented, natural death, which is now the exception, would obviously become the rule.

In support of his theory Metschnikoff looked for analogies in the animal world, where, however, he believes natural death to be somewhat rare. He found one example of natural death in a species of orthoptera, the *ephemera*, which only lives a few days, and undergoes no change which can be regarded as an internal cause of death. It has, however, lost the instinct of self-preservation, since the adult insects allow themselves to be caught without making the slightest attempt at escape, as other insects would do. He regards this behaviour as a phenomenon connected with natural death, and considers that this loss of the *will to live* would be noted in the old of the human species if they really died a natural death. He remarks that on the contrary the diminution and cessation of the instinct of life are very seldom seen; the greater number of old people wish to prolong their lives, dread death, and seek every means of postponing it. This instinct of preservation, this desire to live, has been handed down by an infinite number of generations, and is consequently very widespread and tenacious. We can hold with Darwin and his followers that those who have not looked on life as a benefit have been gradually eliminated before giving birth to others. To the survivors and their progeny life, though not devoid of sorrow, trouble, and evil, is a source of delight; and when they grow old, the memory of bygone joys, the fear of the *unknown* beyond, the dread of *non-existence*, make them cling fast to life and regret the happiness past, even when there is a sense of weariness and suffering, and when the truth of Leopardi's dreary conviction of "the infinite vanity of all things" is borne in upon the soul.

Metschnikoff strives to mitigate this tormenting doubt as to the value of human life, and to exalt the instinct which cherishes it; unfortunately, however, most of the grounds upon which he bases his new optimism are purely theoretical. The necessity of dying and the desire for death as a deliverance are not readily conceivable in physiological old age, which presupposes a long life of comparative happiness. Metschnikoff tries with his theories to give mankind the possible prospect of a voluntary and happy end to bodily existence, instead of the actual ordinary end, which is

always painful, because generally involuntary and morbid; in other words, he endeavours to find a basis upon which to build up a reasonable doctrine of *euthanasia*, Leopardi's *pleasantness of dying*, which afforded the physicians of old, Camerarius, Alberti, Hufeland, Cirillo, and Brodie, so much food for thought.

Let us try to obtain if possible a further insight into the alleged *instinct of death*. Does it really exist? Have we really within ourselves a dim feeling of the approach of death? Ballion (1892) contends for its existence by arguments taken by analogy from the animal world. In many cases he considers there can be no doubt that death is foreseen, proof thereof being the desire for isolation manifested when the natural term of life is approaching. Of greater weight, however, are the arguments adduced by Egger and Sollier (1897), Féré (1898), and Ferrari (1896), all of which are based upon strict observation. Ferrari succeeded in collecting various cases, some of young hysterical subjects, others of insane persons, in whom there was undoubtedly a presentiment, almost a prophecy of death under normal physical conditions.

One case was that of a woman of forty, an inmate of the lunatic asylum at Reggio Emilia suffering from secondary insanity and without a ray of intelligence. This woman suddenly changed her behaviour, began to eat voluntarily, which she had not done for nearly seven years, and seven months later expressed the desire to write to her parents—another thing she had not done for years—made remarks relating to her funeral, although she was in good health, and announced the following evening that she had but four or five days to live, and that she would like to spend them in bed, although she was still in good, indeed in perfect bodily health. Early on the fourth day she died suddenly. A post-mortem examination was not possible, but whatever the internal state of the dead woman may have been, the prevision and accurate prophecy of death were remarkable, occurring in a person in whom every form of sensibility was obtuse.

It is extremely difficult to explain this and other similar cases. The hypotheses of auto-suggestion (Forel) or of a disturbance of general sensibility (Ferrari) caused by some organic injury perceived by the subject before the last agony began do not apply, since death was sudden and not preceded by any morbid symptom.

In the cases collected by Ferrari it is interesting to note the relative indifference with which certain individuals passed through the supreme moment the near approach of which they had foretold. This phenomenon leads us to suppose that death is terrible only because of its associations, and does not in itself affect our sensibility. As a matter of fact the fear of death is not always present. It is found in the large majority of adults, but in children, who have scarcely gazed on the mystery of life, it is but rarely seen.

It is not then the result of an inborn natural law, but an acquired instinct, which torments and obsesses us by reason of the moral and intellectual reflections it brings in its train.

We are thus led to consider the psychical conditions of man during the brief period preceding death. It is a question which has awakened the philosophic curiosity of many writers, amongst whom it will suffice to mention Epicurus, Cicero, Lattanzio, Montaigne, Buffon, and also Leopardi in his admirable *Dialogo di Federico Ruysch e delle sue mummie*.

Many medical reports and searching examinations of individuals who have barely escaped an accidental death have proved to us that death is not *physically painful*, and that from the point of view of the sensations there is no difference between death and falling asleep. *Euthanasia* may therefore be termed a constant phenomenon; the approach of the fate which each one of us bears with him is accompanied by a kind of serene reverie, not by acute pain, as those who are present at an apparently painful death might suppose. Some individuals who have been saved from drowning say that they felt nothing in the supreme moment, others speak of pleasant sensations, others again of vaguely disagreeable but not painful sensations (such as a *sense of oppression in the chest*), others remembered at that moment particulars of their life, long forgotten. The reports of persons who have fallen over a precipice when mountaineering in the Alps are of a like kind: they declare that they never lost consciousness for an instant, that they suffered no pain as they fell from rock to rock, that they thought with extraordinary rapidity of a number of things both past and future, that they heard a sort of pleasant tinkling, and even experienced an indescribable feeling of well-being! The few who die a natural death from old age are said to fall peacefully asleep without a struggle or pain. The centenarian Fontanelle was asked what he felt as he lay on his death-bed. "Rien qu'une difficulté d'être," was his reply. A relation of Brillat-Savarin, aged 93, asked for a glass of water shortly before his death and said to the illustrious author of *La Physiologie du goût*: "Thank you for this last service. If you ever become as old as I am, you will see that death is as necessary to man as sleep."

Worthy of note is the sense of peace and mental lucidity sometimes seen a short time before natural death. Even in maniacs and persons suffering from serious psychical disturbances a flash of consciousness, a momentary recovery of their intellectual powers, has been remarked. Thurnam (1845) drew up statistics and found that this phenomenon occurred in a fourth of the cases of insanity.

More recently Egger, Sollier, Ferrari, and others have observed the phenomenon of *hypermnèsia* in the dying. Egger thinks that the idea of approaching death, working by *contrast*, awakens the

memory of past events. In the case of natural death, which approaches gradually without causing unconsciousness, the dying person passes his career methodically in review and can relate it to those around him. When the end is sudden and accidental, the past probably revives, but does so as a period which has been but cursorily traversed.

Sollier attributes the sense of *euphoria* common in those dying from natural or morbid causes to the functional weakening of the nervous system, which leads to anaesthesia and analgesia; whilst in cases of accidents the attention is turned sharply to the cause which is to end in death, and the patient becomes anaesthetic and analgesic from *distraction*. Féré on the other hand regards the reawakening of the intelligence and moral tone of the dying as a *hyper-excitement* of the nervous elements which are about to be deprived of their vital properties, an excitement which may be compared to the last contraction which precedes the advent of rigor mortis, and is the last vital act of muscles. Both these phenomena are probably due to an accumulation of toxins or of the waste products of the tissues as a whole.

Whatever may be the truth of these ingenious explanations, observation of the phenomena of the last moments of life gives us the right to conclude that dying is not physically painful and that in the majority of cases *euthanasia* is a normal phenomenon.

If we can succeed in eliminating not only physical but also mental pain we shall attain the ideal, a *good, gentle, calm death*, such as that preached by Maurice Maeterlinck. Could we learn to regard death itself, freed from material horrors and imaginary fears, it would seem to us calmer and more serene. "As a well-spent day makes us glad to sleep, so a well-spent life brings a happy death," says Leonardo da Vinci. It is not so much the dissolution of the body as the extinction of *personal consciousness* which moves and distresses men (especially men of a higher order) and makes them turn pale in the presence of death. Doctors advise two specific remedies—*philosophy* and *religion*—for this *fear of death* which afflicts humanity, not so much in the last moments when the senses are dulled and the consciousness clouded, but on every grey day, at every sad domestic event throughout life.

Our illustrious Greek scholar, Comparetti, edited in 1885 a noteworthy fragment of Epicurus taken from a papyrus found in Herculaneum. In this fragment the Greek philosopher, summing up his doctrine of happiness (*eudaemonia*), which he regards as consisting in the untroubled serenity of the soul (*ataraxia*), tells his pupil that he must always have with him and hold in his hand what he calls the *fourfold remedy* (*tetrapharmakon*), namely: *God is not to be feared; death is not to be a cause of worry; good is easy to follow; evil easy to bear*. With reference to the maxim

about death, Comparetti points out that Epicurus regards it merely as a terrifying thought or reflection from which we must free ourselves, and calls to mind the principle which he enunciated in the *Chief Principles*, the summary of his teaching, the one which has been expressed by Diogenes Laertius in these words: "Death has nothing to do with us, since that which is destroyed does not feel and that which does not feel has nothing to do with us." In the letters to Meneceus (by Diogenes Laertius) the philosopher declares and explains this principle, saying: "Every good and every evil is a matter of sensation; death, therefore, which suppresses the senses, suppresses with them both good and evil for man." Hence the philosopher, arguing along these lines, ends by formulating his maxim in these more concise terms: "*Death has nothing to do with us, because when we exist, it does not; when it exists, we do not.*"

"To philosophise is to learn to die," wrote Montaigne about eighteen centuries after Epicurus; unfortunately, however, the methods which he proposes in his *Essais* to enable us to grow accustomed to the idea of death and to conquer fear of it seem a mockery. When he says to those who are afraid to die: "*La mort ne devrait pas vous affliger ni vif ni mort; vif, par ce que vous estes; mort, par ce que vous n'estes plus,*" he is repeating the maxim of Epicurus almost word for word; this, however, is an elegant sophism better suited to an orator than a philosopher. It is just the prevision or doubt of *non-existence*, "*la pensée du néant,*" which torments us during our life-time and prevents our full and constant enjoyment of existence, *i.e.* of life.

The really heroic remedy for the fear of death is religion. Buddha's moral teaching exhorts man to forget death altogether and to believe himself immortal, so long as he devotes himself to the acquisition of wisdom and virtue. All religions owe their millions of converts to the doctrine of *immortality* or at least of the *survival of the soul* after the dissolution of the body, which removes the fear of death, and even, in the case of their most fervent disciples, replaces it by the *desire for death*, which they look upon as a deliverance, opening the door to a better and higher life.

Let us glance at Domenichino's picture of St. Jerome (Fig. 128), who has reached the *last moment of his long life* and is about to receive the Viaticum. His emaciated countenance wears the calm expression of one who puts off his mortal vesture with no regret; but on the other hand there is the melancholic languor of one who, while he has no doubt of the better life awaiting him, is uncertain whether he has written, disputed, fought and suffered enough to deserve it! Sublime mediaeval asceticism, with a faith in an imaginary life beyond so fervid that it prevented the recognition of the value of real life!

Neither this sublime religious sentiment nor this contempt for physiological life is, however, necessary in order to take away the fear of death. Belief, or at all events a suggestive hope in the *survival of human personality*, is independent of any religious



FIG. 128.—The Communion of St. Jerome. (Photograph by Alinari, Florence.)

creed and does not differ essentially from faith in the future of humanity, the beneficial effect of virtue or the ideal of science and art. It will suffice to recall the heroic death of Socrates as recorded by Xenophon, and in more modern times the calm, we might almost say joyous, death of the author of *Human Personality* (F. W. Myers), who died in Rome on January 17,

1901. William James, who was in Rome at the same time as Myers and was with him during the last weeks of his life, writes in a letter to Podmore announcing his death: "His demeanour throughout the illness has been superb, showing how a really living belief in immortality will help a man." The illustrious physicist, Oliver Lodge, describes the death of Myers in the following words:

"The termination of his life, which took place at Rome in the presence of his family, was physically painful owing to severe attacks of difficult breathing which constantly preceded sleep; but his bearing under it all was so patient and elevated as to extort admiration from the excellent Italian doctor who attended him; and in a private letter by an eye-witness his departure was described as 'a spectacle for the Gods; it was most edifying to see how a genuine conviction of immortality can make a man indifferent to what to ordinary people is so horrible.' . . .

"Death he did not dread. That is true; and his clear, happy faith was the outcome entirely of his scientific researches. The years of struggle and effort and systematic thought had begotten in him a confidence as absolute and supreme as is to be found in the holiest martyr or saint. By this I mean that it was not possible for any one to have a more absolute and childlike confidence that death was a mere physical event. To him it was an adversity which must happen to the body, but it was not one of these evils which may assault and hurt the soul. An important and momentous event truly, even as birth is; a temporary lapse of consciousness, even as a trance may be; a waking up to strange and new surroundings, like a more thorough emigration than any that can be undertaken on a planet; but a destruction, or lessening of power no whit. Rather an enhancement of existence, an awakening from this earthly dream, a casting off of the trammels of the flesh and putting on of a body more adapted to the needs of an emancipated spirit, a wider field of service, a gradual opportunity of re-uniting with the many who have gone before. So he believed on what he thought a sure foundation of experience, and on the strength of that belief he looked forward hopefully to perennial effort and unending progress. . . .

"Such was his faith; by this he lived, and in this he died. Religious men in all ages have had some such faith, perhaps a more restful and less strenuous faith; but to Myers the faith did not come by religion: he would have described himself as one who walked by sight and knowledge rather than by faith, and his eager, life-long struggle for knowledge was in order that he might by no chance be mistaken."—*Proceedings of the Society for Psychical Research*, vol. xvii., 1901-3, p. 5.

In order to ensure ourselves this *ideal euthanasia* we have but to convince ourselves that *materialism* is utterly unable to afford

any explanation of the most ancient problems of man and the universe; belief in *philosophy*, in the spiritualistic or even the idealistic hypothesis, is all that is needed to enable us to estimate life aright and to look death in the face, if not with a smile on our lips, at all events with calm resignation and confidence based upon hope.

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CHAPTER VIII

THE HUMAN RACES¹

SUMMARY.—1. Relationship between physiology and *ethnology* and *anthropology* (*somatic* and *psychic*). 2. Morphological characteristics of the different existing races. 3. Functional variations of the circulatory and muscular systems in the different existing races. 4. Functions of the whole organism of the different races. 5. Physio-psychological characteristics; organs of sense, language and psychic capacity. 6. Prehistoric civilisation and the development of psychic activity proved by *palethnology* and *comparative ethnology*. 7. Origin and development of the different human races. 8. Classification of human races. Bibliography.

FROM time immemorial man has been cosmopolitan. The capacity of the human organism to adapt itself to the most widely different conditions and environment is nothing short of marvellous; with the exception of the polar regions there is almost no part of the world from the torrid to the frigid zone in which man has failed to become acclimatised and to find everything requisite for the normal development of his functions. This adaptability distinguishes man from all the other higher mammals (with the possible exception of his faithful friend and companion, the dog) and is undoubtedly mainly due to the high state of development of his cerebral functions which enables him, wherever he may be, to turn to the best account all those conditions which are favourable to his existence, and to avoid harmful influences. In the arctic regions he has clad himself in warm furs as a protection against the cold, and in every climate he has obtained nourishment from roots buried in the earth, from fruit, and from the flesh of beasts and fish. His urgent need of food has taught him how to place himself less at the mercy of his surroundings by *fishing* and *hunting*—the first stage of civilisation; by breeding cattle and sheep—the *pastoral* or second

¹ This chapter is, as it were, an *appendix* to my work on physiology, which would have been lamentably incomplete had I failed to give a brief summary of the more important results obtained by the new branches of science known as *anthropology* and *ethnology*. In order not to delay the completion of my work unduly I entrusted this chapter to my able assistant, Professor S. Baglioni, who has, as is well known, included these collateral branches of the science of man in his extensive studies. My share has been confined to bringing his work into harmony with the rest of the book.

stage; and finally by *agriculture*—the cultivation of useful plants, which ethnologists regard as the basis of all civilisation. We have no intention of dwelling upon the gradual development of human civilisation, a task which belongs to the *ethnologist* and the *anthropologist*; we merely propose to give a brief summary of the structural and functional variations of the human organism which have been noted in the different races at present inhabiting the various parts of the world.

The modern biologist, who is rightly accustomed to regard outward conditions as so many factors which may influence and modify the vital manifestations of organisms, will in theory expect to find that the functions of man, too, will be influenced and modified by his environment. If we further take into consideration that anthropologists of standing consider that the different races are not all descended from one and the same stem, but have arisen from different types which originated independently of one another in different parts of the world, we shall readily understand that the functions of individuals belonging to different races may be subject to variations due not only to the influence of external factors but also to that of internal, original, and congenital factors, inherent in their organisms.

The study of the functional variations in the different races will therefore appear not only justifiable but also likely to yield a large harvest of interesting results bearing on the solution of the complex problem of the origin of our civilisation. Unfortunately nearly everything still remains to be done; we are well acquainted with the more important data of the physiology of our own races, but know little or nothing of those of others.

As was well observed by Virchow in 1886 when discussing the problem of the acclimatisation of single individuals and of different races—the main cause of the success or failure of colonies in which the climate differs from that of the mother country—many difficult questions must be considered and answered before we can form a scientific theory of *acclimatisation*, based upon the study of those variations in physiological processes which are brought about by a change of dwelling-place. Modern scientists incline more and more to the belief that physiology will help us to solve the problems of anthropology and sociology. Zeligson (1912), having proved that the sociology of to-day shows a marked tendency to state and solve its various problems in terms of physiology, asserts that we must in future attach great importance to the methods and problems of pure physiology if we would study social phenomena by the strict method used in the study of natural science.

The task assigned to this new science, to which he gives the name of *social* or *socio-physiology*, is the study of the reflex

reciprocal reactions of single individuals living together as a social whole, and also of the way in which they react to the influence of external environment, etc. Its province would therefore be more especially the study of the functions of the central nervous system. Zeligson lays special stress on the importance to sociological physiology of Pavlov's conditioned reflex actions.

Whilst, however, we admit that the study of the nervous functions in social aggregates should take the prominent place accorded to it in the study of the physiology of the individual organism, we cannot lose sight of the fact that social physiology should rest upon a broader basis, and include all the problems of individual physiology which we have already considered, whilst laying no claim to be alone capable of affording a final and satisfactory solution of these problems. Social problems are of such a complex nature that many and various sciences must join forces and co-operate in the endeavour to solve them. No one, however, will venture to deny that considerable assistance may be expected from the application of physiology to the study of anthropological, ethnological, and social phenomena.

Giuseppe Sergi (1910), the pioneer of anthropological science in Italy, recognises that anthropology has as yet only reached an elementary stage, and rightly asks that its progress may be assured by the application to it of the methods of natural science, whether of zoology or of botany. We are indeed aware that the anthropological results so far attained by the numerous workers in this field are very poor, as compared with those reached in the other natural sciences. This is undoubtedly due to the fact that the methods of observation hitherto employed in anthropology, such as craniology or craniometry, the study of the various more superficial characteristics of the human body, of the manners, customs, and civilisation of different peoples, etc., are lacking in the precision of the other sciences, physiology amongst them, which aspire to rank as exact natural sciences.

In like manner physiology, as the science of individual functions, obtains data and information of great assistance in the solution of its problems from the observations of pure anthropology and ethnology. Knowledge of the kinds of food consumed by different peoples, for example, has done much to further the solution of the problem of nutrition. Individual psychology may derive even greater profit from knowledge of the customs, beliefs, ideas, and opinions of different races. We shall of course confine ourselves in this chapter to those data which are more or less closely related to physiology. They are neither numerous nor of the first importance to physiology, since we are indebted for most of them not to medical men or biologists, but to travellers and explorers, of whom even the most competent, though undoubtedly expert anthropologists or ethnologists, were not qualified to make those

observations which would be of the greatest importance from the physiologist's point of view.

II. We must first of all describe those specially striking characteristics which enable us to distinguish and classify the different races. One of the characteristics to which the earliest anthropologists attached very great importance is the colour of the skin, iris, hair, and beard. The distinguished histologists, Kölliker and Virchow, discovered this difference of colour to be due to the greater or smaller number of granules of pigment contained in the cutaneous cells, and more particularly in the deeper cells of the Malpighian layer (Vol. II. Chap. IX.).

Virchow maintains that there is no human race whose hair, iris, and skin are totally devoid of pigment; true albinism is a pathological condition (*leucopathia*); hence the differences existing between the various races in this particular are merely ones of degree, and not even the most careful and detailed study can draw a line of demarcation between individuals belonging to different races.

The action of the sun has always been known to exercise a great influence on the colouring of the different races. The nearer man lives to the equator, the darker does the skin tend to become. In the case of individuals leading an out-of-door life in our own climate we notice that those portions of the skin which are exposed to the sun become more or less brown. It would not, however, be accurate to say that the black or brown colour of the skin is due only to the action of the solar rays. Virchow points out that, though in America there are tropical and frigid zones just as in the old world, that continent possesses no races as black as the Kaffirs or as fair as Anglo-Saxons. In Northern Europe we have the Finns who are fair, and still farther north the Laplanders who are light brown. In all probability the colour of the skin depends not only on external conditions, such as climate and environment, but also on internal causes, such as the specific congenital tendencies of the different races.

Some modern anthropologists—Topinard and Deniker amongst them—distinguish *ten gradations* in the colour of the skin. There are gradations amongst the *white* races: pale and rosy white, found amongst Scandinavians, English, Dutch, etc., and brunette, found amongst Spaniards, Italians, etc. The *yellow* races likewise present three varieties of colour: light yellow, fallow, and corn coloured, seen in certain Chinese races; opaque yellow, tending to olive, the colour of a new leather, seen in the natives of South America, Polynesia, and Indonesia; golden brown, the colour of a dead leaf, seen in the Malays and certain American races. There are at least four gradations of colouring amongst the *black* races: reddish brown or cinnamon coloured, amongst the Beggia, Niam-Niams, etc.; chocolate, such as the Dravidians, Australians, and certain

negro and Melanesian races; very dark brown and coal black, as in various negro races.

Anthropologists, in order to avoid misunderstanding in the indication of the colour of the skin of the different races, make use of a colour scale in which the various gradations are distinguished by means of numbers. Of these shade cards, Broca's, which shows 34 gradations, is the best and the one almost universally adopted.

It is nevertheless by no means difficult to make mistakes when judging the natural colour of the skin. Many uncivilised races are in the habit of imparting an artificial colour to the skin; this artificial colouring is sometimes connected with the process of *tattooing*, sometimes quite independent of it. The first European explorers who saw American Indians described them as copper coloured; this colouring proved, however, to be artificial and to result from the custom of the Indian braves of smearing the skin with a red dye before starting on any warlike enterprise. The natural colour of the skin of the natives of Melanesia is suffused with pink or brown owing to their habit of rubbing red earth or soot into the skin; a bronze hue may be imparted to the skin by a more or less thick layer of dirt which is never removed, as in the case of the natives of Tierra del Fuego. A prolonged sojourn in dark places far removed from the action of the solar rays will gradually reduce and attenuate the dark pigment in the skin of coloured peoples, as may be seen amongst the adherents of a male sect existing amongst the inhabitants of New Mecklenburgh, whose rule obliges them to live for months together during the daytime in low dark huts, which they are only allowed to leave at nightfall (Schlaginhaufen).

A special characteristic of the Mongolian races is the so-called *blue mark* on infants, first noticed by Balz in 1883 on Japanese children. This cutaneous mark is grey-blue in colour, round or oval in form, with a diameter of from 0.5 to 5 cm. and is situated above the coccyx; it disappears during childhood. It occurs most frequently amongst Mongolians, of whom 80-90 per cent have it, but is also seen on children of other coloured races (Ainu, Samoan, Negro, Indian); in these cases, however, it is blackish in colour; it is also very occasionally seen on European children of non-Mongolian races (0.04-0.05 per cent according to different observers).

Three fundamental grades of colouring prevail in the *iris*: light (blue or grey); dark (light or dark brown and black); intermediate (green, yellow, yellowish grey, etc.). Light eyes, blue or grey, are to be seen only amongst the fair European races, possibly also amongst Turco-Finnish peoples; certain Mongolian races have light brown eyes, all others dark brown or black.

There are four main gradations in the colour of hair: black,

brown, medium or chestnut, and fair. Fair hair may be either golden or flaxen; it is specially characteristic of the peoples of Northern Europe. Red or auburn hair cannot be regarded as characteristic of any one race, but must be looked upon as an individual peculiarity; it is generally accompanied by freckles and is seen in countries where there is a crossing of two races, dark and fair. It is, however, sometimes met with in persons belonging to a pure dark race where no such crossing has taken place, as in the case of European Jews (Broca's Erythism). The hair and beard vary also in length and form in different races. Some observers, Haeckel and Friedrich Müller amongst



FIG. 129.—Types of hair (Virchow). 1, Smooth; 2, wavy; 3, spiral; 4, woolly.

the number, consider this characteristic to be of the utmost importance, to be indeed a differential characteristic on which, as we shall see later, their classification of the human race is based.

The hair falls into two main categories as regards its form: woolly (*ulotrichi*), having an oval transverse section, and smooth (*lissotrichi*), having a round transverse section. Each of these classes may be further subdivided into two classes (Fig. 129): woolly hair growing in tufts and hence not uniformly distributed over the head (*lofocomi*), like the hair of Hottentots and Papuans, and woolly fleecy hair, evenly distributed over the head (*ericomi*), such as that of African negroes; smooth or straight, not growing in ringlets or curls (*euticomi*), like that of Australians, Northern Europeans, Americans, Malayans, Mongolians; smooth hair

growing in ringlets accompanied by a more luxuriant beard (euplocomi), such as is seen in Dravidians, Nubians, and the peoples of the Mediterranean.

Comparative study of the human skeleton, and more particularly of those parts which are more highly developed in man, *i.e.* the skull and facial bones, has brought to notice other characteristics distinguishing the different races. Craniology has undoubtedly been of great service to anthropologists; we must not, however, fall into the error of certain scientists in times past, and regard it as the basis upon which anthropology rests. We will not enter minutely into this subject, which is the province of

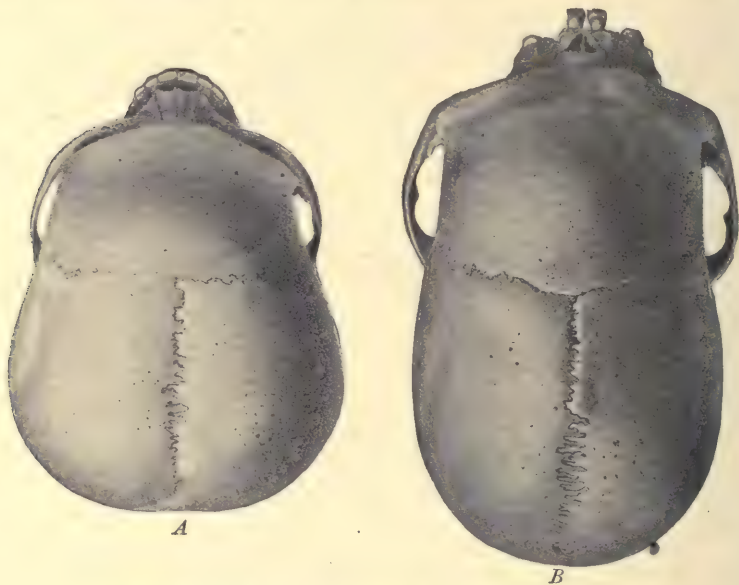


FIG. 130.—A, Brachycephalic skull; B, dolichocephalic skull.

works devoted entirely to it, but will confine ourselves to the more important facts brought to light by craniological research. We first note the difference in the shape of the skull. The two extremes are known as *dolichocephalic* (long-headed people) and *brachycephalic* (short-headed people). In the former case the skull seen from above is elliptic in shape, the greatest diameter being from the forehead to the nape of the neck; it therefore appears lengthened from the front to the back and laterally compressed. In the case of the *brachycephalic* on the contrary the circumference of the skull tends to become spherical, being relatively compressed from the front to the back and projecting more towards the sides (Fig. 130). Between these two extreme

types of cranial formation we have a large number of intermediate shapes known as *mesocephalic* (medium-headed people).

In each of these three groups we find some who are *prognathous* (oblique jawed), in which the jaws project as does the snout of the lower mammals and the incisors slope outwards, and others who are *orthognathous* (straight jaws or teeth), in which the jaws are less developed and prominent, so that the incisors are vertical (Fig. 140).

We have also two extreme types in the shape of the whole face, just as in that of the skull: the long narrow face (*dolichoprosopia* or *leptoprosopia*) and the short broad face (*brachyprosopia* or *prosopia*) (Kollmann and Ranke, Fig. 131).

When forming an estimate of the different normal morpho-

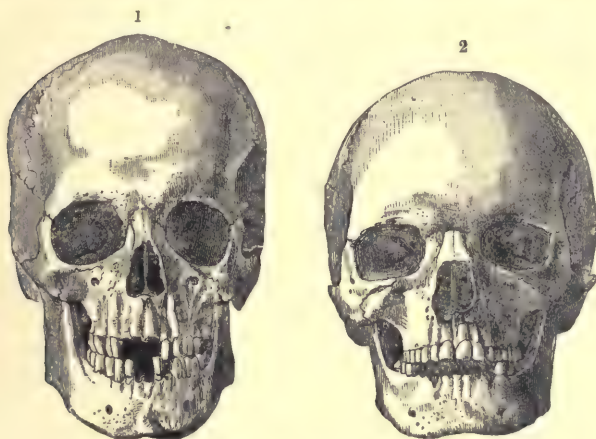


FIG. 131.—1, Narrow or dolichoprosopic face; 2, broad or brachyprosopic face. (Kollmann.)

logical characteristics, and more especially of those of the skull, we must of course eliminate the effects produced by pathological modifications, such as microcephaly, hydrocephaly, scafocephaly, acrocephaly, plagiocephaly, clinocephaly, due for the most part to embryonic or post-embryonic changes occurring during the ossification of the different bones of the skull; we must further eliminate the results of artificial deformation of the skull, such as is customary amongst various races of America (Indians), Australia (New Hebrides and New Britain), and Europe (Normandy and Brittany), which are brought about by means of compression with bandages in infancy when the skull is in process of development and still soft.

Amongst other bodily characteristics is the formation of the *retrosacral fossa*, which the investigations made recently by L. Bolk amongst the Dutch and Melanesians, and those of

S. Sergi (1912) amongst the Italians, Albanians, Prussians, pre-historic Egyptians, inhabitants of Tierra del Fuego, Peruvians and Bolivians, show to be considerably deeper amongst all civilised races.

The retrosacral fossa is the cavity in the pelvis formed by the posterior superficies of the sacrum, and laterally circumscribed by the post-articular portions of the iliac bones. Sergi considers these variations in the retrosacral fossa to be of "a physiological nature, *i.e.* the expression of a functional correlation with a whole system of different morphological conditions in the skeleton; the reduction of the retrosacral fossa is not peculiar to the Melanesians (as is thought by Bolk), neither does it point to typical carriage amongst those peoples, but rather to static and dynamic physical conditions, common to all primitive peoples." He further remarks that similar differential variations in the skeletal system of the trunk (vertebral column and ribs) were noticed at an earlier date. In 1887 Sergi remarked that the curvature and degree of torsion of the ribs of the inhabitants of Tierra del Fuego are not the same as in Europeans, for which reason "their thorax is laterally narrower than that of Europeans, and projects more towards the front."

Cunningham and Manouvrier noticed differences in the characteristic curves of the vertebral column connected with the erect position of the human form. In like manner it has been observed that in the course of general development amongst Europeans the retrosacral fossa, which is shallow in the infant, becomes deeper and deeper during the first years of extra-uterine life, just as the curves of the spinal column become more and more marked.

Hitherto the researches of anthropologists have been almost entirely confined to the different parts of the skeleton (and more especially of the skull), because the skeleton can be preserved without difficulty for the purpose of such research. It is, however, obvious that somatic anthropology, like comparative anatomy, which has achieved notable results by proceeding from the study of the skeleton to that of the other systems and organs (muscles, nerves, intestines, etc.), must in future investigate in various human types the differential characteristics found in the other anatomical systems, or rather in the soft parts. We may mention that this study has been begun by several anatomists, amongst others Chudzinski, Giacomini, and Loth, who have studied the muscular system of negroes, and Adachi, to whom we are indebted for an excellent work on the muscular system of the Japanese. Loth has recently summed up the results of these first researches, and drawn the following conclusions therefrom.

I. We must admit the existence of indubitable morphological

differences between white races and negroes on the one hand, and negroes and Mongolians (Japanese) on the other.

II. The negro is proved to be at a lower philogenetic stage than the European, *i.e.* he presents morphological characteristics of a more primitive order.

The following table shows our present knowledge of the most important differences between Europeans, negroes, and Japanese :

NECK.				Europeans.	Negroes.	Japanese.
				Percentage.	Percentage.	Percentage.
<i>Sterno-hyoideus</i> :	<i>inscriptio tendinea</i>	present	.	1·5	6·6	70·7
<i>Sterno-thyroideus</i>	"	"	.	...	22·2	65·0
TRUNK.						
<i>Sternalis</i>	present	.	.	4·1	12·5	15·8
<i>Pyramidalis</i>	present	.	.	85·0	89·1	96·0
UPPER LIMB.						
<i>Biceps Brachii</i> :	<i>Caput tertium</i>	present	.	9·1	12·5	15·7
<i>Palmaris longus</i>	present	.	.	44·0	48·3	49·5
LOWER LIMB.						
<i>Psoas minor</i>	present	.	.	44·0	48·3	49·5
<i>Gemellus superior</i>	present	.	.	92·0	93·0	100·0
<i>Plantaris</i>	present	.	.	92·9	94·7	89·0
<i>Peronaeus tertius</i>	absent	.	.	8·2	9·6	4·5
<i>Flexor dig. brevis</i> :	tendon for the fifth toe	.	.	79·5	81·9	75·6

It follows that the negro occupies a position between the European and the Japanese, with the exception of three muscles of the lower limb (*plantaris*, *peronaeus tertius*, *flexor dig. brevis*).

With regard to the variations of the eleven muscles indicated in this table, the negro presents characteristics of a more primitive order than does the European. The case of the Japanese is very different; we notice a difference in the sterno-hyoid muscle, but the most striking fact about the Japanese is, that while the body as a whole shows a more primitive structure than that of either the European or the negro, the muscles of the lower extremities are more highly evolved than those of the two other races. This fact was pointed out by Adachi; Loth considers it difficult of explanation; we are forced to admit that the Mongolians, whilst the most primitive as regards the body as a whole, have reached the highest stage of evolution as regards the lower limbs.

Loth, in support of the inferiority of the muscular morphological characteristics of the negro as compared with the European, adduces a number of racial differences which cannot be numerically expressed. From a comparative table it results that the negro clearly shows primitive characteristics as compared with the European in 32 out of 44 muscles. Amongst these may be mentioned the ocular muscles, which are less differentiated, although highly developed; the relative frequency of irradiation in the nape region of the *platysma myoides*, the crossing of the two

muscles *quadrati lab. inf.* in the centre; the remarkable development of the zygomatic arch; the indefinite outlines of the *orb. oculi* muscles; the singularity of the *quadr. lab.* in the width of the *sterno-hyoid* and *sterno-thyroid* muscles; the tendency to median crossing shown by the *pectoralis major* muscle; the increase in the tendinous insertions of the *rectus abdominis*, and its nearer costal insertion; the shortening of the *trapezius* muscle; the enlargement of the *splenius*; the extraordinary variability of the sacro-spinal muscular system; reductions both in extent and volume, besides tendencies to anastomoses in certain muscles of the fore-arm.

The principal forms of the nose, judged by the length and breadth of the nose and nostrils, are *leptorrhinous* (long nose) and *platirrhinous* (broad nose); the intermediate forms are known as *mesorrhinous*. The eye is of two different shapes, that seen in Europeans and the *slanting* or *Mongolian* eye (Fig. 132).



FIG. 132.—1, European eye; 2 and 3, Japanese eye, Mongolian type. (Balz.)

Another constant physical characteristic of the various races is their height measured from the head to the soles of the feet. This characteristic has hitherto been regarded as of merely secondary importance, because it was supposed to vary immensely in individuals belonging to the same race; this view Deniker holds to be wrong, since there are fixed racial limits to these variations. Infants born in Paris are on an average two millimetres taller than those born in St. Petersburg, their heights being 499 mm. and 477 mm. respectively.

The available statistical data on this subject are, however, inadequate, especially in relation to the height of non-European races.

The extreme limits within which the height of the individual varies are supposed to be 125 and 199 cm. for the normal male adult; below and above these limits we find the pathological conditions known as *nanism* and *gigantism*. It is, however, extremely rare for an individual to reach either of these limits;

a person measuring less than 135 cm. or more than 190 cm. may be regarded as exceptional. Gould's American statistics, taken in 1869, the result of measuring 300,000 individuals, show that of 10,000 only one was a giant—only one, that is to say, measured over two metres, and barely five per thousand over 190 cm. On the other hand, only one person out of 100,000 measured less than 135 cm. This example is taken from the statistics of a comparatively tall nation, attaining on an average a height of 172 cm. The statistics compiled by Pagliani in 1879 refer to a comparatively short race—the Italians. Amongst 7000 persons he found only one attaining a height of 199 cm. or over, whereas three in a thousand were under 135 cm. in height.

As is well known, there are pigmy races in Africa (Accas) whose average height is 138 cm., and very tall races, like the Scotch of Galloway and the north, whose average height is 178 to 179 cm. (Deniker).

Leaving these extreme cases out of consideration, we find that the average height of the various races inhabiting the globe is from 146 cm. on the one extreme to 175 cm. on the other. If we further eliminate certain very short races (the so-called Negritos, found in Acca, Aeta, the Andamans and Semang), we find that the rest of humanity attains an average and gradually increasing height of from 154 to 175 cm., the average figure being 165 cm., as was found by Topinard, who proposed to classify height as follows: (a) small, under 160 cm.; (b) under the average, between 160 and 164.9; (c) over the average, 165 to 169.9; (d) tall, from 170 to 175 cm.

There has been much discussion as to the origin and characteristics of the African pigmy races, some anthropologists regarding them as the representatives of a single human race of the sub-dolichocephalic type, from which the taller races are derived. Poutrin's excellent work (1911–12) relating to the African pigmies, the so-called Negrillos and Negritos, has, however, proved this theory to be mistaken, and upset the hypothesis that all these pigmy peoples belong to one and the same race.

He states that there are as many pigmy races as tall ones and that there are no connecting links between them. It is more especially wrong to regard the Negrillo and Negrito groups as a single race. The Negrillos are the representatives in Africa of the race incorrectly termed pigmy, which is very far from being homogeneous not merely in Asia and Africa but also in the groups of the great equatorial forest. The alleged infantile characteristics of the Negrillos (Kollmann and Schmidt) cannot be admitted; still less can they be taken to represent an initial period in human evolution.

Since we are unable to ascertain the origin of the Negrillos, we can only state that they inhabited Africa before the Negroes,

how long before we do not know, or whether they are an aboriginal race. The Ba-Bingas may be regarded as forming a distinct group of a special race: we cannot trace them back to the negro type or regard them as the predecessors of the *homo primigenius*; it may one day be possible to admit the development of both short and tall races to have taken place at the same time.

The Anthropometrical Commission of the British Association has recently published the average height of the different

European nations. Anglo-Saxons rank first, the English and Norwegians measuring on an average 170 cm.; next come Danes, Dutch, and Hungarians with 167 cm.; Swiss, Russians, and Belgians measure about five millimetres less; last of all we have Italians and Spaniards, who average 165 cm. Verwaeck (1909) considers that the average height of the Belgians has varied considerably during the last twenty years; on the whole it tends to increase. Other morphological characteristics of the human body seen in certain races are *steatopygia* (an abnormal accumulation of fat in the posterior regions, Fig. 133) and the *apron* (an abnormal development of the labia minora, which become pendulous appendages several centimetres in length), characteristics seen in Hottentots and Bush tribes.



FIG. 133.—Afandi Bushwoman. (G. Fritsch.)

There is one class of morphological characteristics to which we must ascribe great importance, namely, the characteristics of the brain. Starting from the assumption that the stage of civilisation reached by different races depends essentially upon the greater or lesser degree of activity of the grey matter of the brain, it clearly follows that the demonstrable differences in the morphological characteristics of the brain may to a certain extent be regarded as conditions related to the higher or lower stage of civilisation. Of the various morphological characteristics of the brain, two—*weight* and *shape*—have been the object of special study. Von Bischoff drew up a table showing the average weight of the brain in the different races, part of which we reproduce here.

Bushwomen	997 grms.
Natives of Bombay	1006 "
Hindus	1176 "
Negresses	1202 "
Negroes	1232 "
South Germans. Women	1220 "
South Germans. Men	1361 "
Chinese Women	1290 "
Chinese Men	1428 "

These figures show the average weight of the brain to be smaller in races whose civilisation is at a lower stage of development—such as Bush tribes and Hindus—than in more highly civilised races such as the Chinese and Germans. Much painstaking and careful investigation of the relation of the weight of the brain to psychical development has nevertheless proved that it would be inaccurate to say that a heavy brain always implies a higher development of the intellectual functions. It is true that the average weight of the brain of great scientists is greater than that of Europeans (which Bischoff estimates at 1350 to 1360 grms.), but it is also true that the brain of some great men weighed less than the average (1207), just as it is true that extraordinarily heavy brains have been possessed by ordinary workmen—Rudolphi instances the case of an absolutely unknown man named Rustan whose brain weighed 2222 grms.

Attempts have also been made to deduce the weight of the brain from the size of the skull, but so far this method has failed to give satisfactory results.

The *shape* and development of the convolutions of the brain in the different races have also been an object of study; the results have not, however, as yet been sufficient to allow of any definite conclusion being drawn from them. Let us take Sergi's recent (1909) examination of the brains of the Hereros, African tribes inhabiting the German colonies. Sergi came to the conclusion that whilst it cannot be said that there is any morphological characteristic of the sulci of the brain which is peculiar to any one race, yet there exist certain racial and sexual differences which occur more or less frequently. For instance, the brains of Hereros as compared with those of Europeans show the following main characteristics: a notable predominance of the simple forms of the posterior termination of the fissure of Sylvius over those which are bifurcated; a greater frequency of the opening of the fissure of Rolando on the medial surface; the less frequent occurrence of numerous divisions of the frontal sulci; a greater frequency of a continuous medio-temporal sulcus; the invariable presence of the rhinoencephalo-temporal gyrus.

Still more recently (1913) Sergi extended his morphological analyses of the superficies of the frontal lobe to the brains of Indians and Japanese, and arrived at conclusions which to all

intentions and purposes agree with those he had already reached. He found that the upper frontal sulcus is more frequently divided in Hereros than in Indians and Japanese, whereas this division is less frequent in the median frontal sulcus; also that the single precentral sulcus occurs more frequently in Hereros and Japanese than in Indians, and that it is very seldom found in Esthonians, Lithuanians, and Poles; that the upper frontal sulcus is never entirely separated from the precentral sulcus in Indians, whereas this separation occurs most frequently in the inhabitants of Java and is rather rarer in Hereros and Japanese; that the lower precentral sulcus usually joins the lower frontal sulcus in the Dutch and Swedes, frequently does so in Japanese and still more often in Poles, Esthonians, Lithuanians, but is never so joined in the brains of Japanese; it is least often seen in Hereros, in whose brains separation with a superficial bridge predominates, whereas in Indians separation with a deep bridge is commoner; that a larger number of paramesial frontal sulci is found in Japanese brains; that the lower frontal sulcus is more frequently divided in Indians and Japanese than in Hereros and Swedes; that the frontal marginal sulci are more divided in Indians and Japanese, less in Hereros, and still less in Europeans. There are also variations in the fissure of Rolando, which have apparently a relation to sex.

Another fact to which Sergi (1910) attaches great importance is the development of the frontal lobe. This development varies considerably, but does not correspond to the degree of intellectual and social development reached by the different races. Great development of the frontal lobe as compared with that of the parietal and occipital lobe does not, therefore, as is thought by many, distinguish the brain of the higher races from that of the lower ones. This suggests that the frontal lobe is not the anatomical seat of the highest psychical functions—a statement in agreement with the conclusions arrived at in the last chapter of Vol. III., in which we proved these functions to be localised in the central and posterior regions of the cerebral cortex.

Kohlbrugge (1911) considers that the results hitherto obtained do not justify the conclusion that the weight of the brain, the complexity of its convolutions, and the size of the frontal lobe invariably increase in proportion to the degree of civilisation or intelligence reached by either individuals or races.

A question of the highest importance which is very frequently discussed is the permanence of different morphological racial characteristics. That there is no such thing as absolute unchangeability is clearly proved by the possibility of crossing different races, the results of which are the well-known half-breeds or mulattos, whose characteristics are a mixture of those of both parents. It is, however, open to question whether these half-

breeds preserve the hereditary characteristics for any length of time or are capable of becoming a half-bred people, properly so-called. The study of such races tends rather to prove that these half-breeds are not capable of such development, but tend to degenerate, and that the greater the difference between the two parents, the more readily does this degeneration take place.

It is, however, generally held that many causes contribute to the changes which take place in the morphological characteristics of a people owing to intercourse with other nations: amongst others we may mention the invasion of a country by armed foes, such as the repeated incursions of barbaric tribes into Italy after the fall of the Roman Empire, and the peaceful immigration of workmen in search of employment, of which we have an example in our own day in the immigration of Italian agricultural labourers in South America. R. Livi regards slavery to have been a no less important factor, and points out its influence in the Middle Ages on the anthropological characteristics of Italians, amongst whom it is by no means rare to see Mongolian or Mongoloid characteristics, which he traces to the Mongolian women who were frequently imported as slaves in the Middle Ages, more especially by the marine republics of Venice and Genoa.

The Italian people is usually regarded by anthropologists and ethnologists as the result of the mingling of various races which immigrated to the peninsula at different times, both prehistoric and historic, and of which at least two belonged to widely different types, one being dolichocephalic and dark, the other brachycephalic and fair, as is shown to this day by anthropological study of Italians from different parts of the kingdom. We are indebted to R. Livi (1896, 1905) for our most accurate information on this subject, information based by him on the data afforded by the military returns relating to conscripts.

Taking, for instance, the question of height, Livi showed that there are at present three districts whose inhabitants are tall, all three in northern Italy. First comes Venetia, where there is a large admixture of Illyrian blood; next, northern Tuscany and eastern Emilia; lastly, northern and eastern Lombardy. These regions show the effect of the constant immigration of tall races from central and northern Europe which went on until the Lombard invasion. The inhabitants of Sardinia, a large part of Sicily, the coast of the Adriatic, and mountainous regions which did not suffer from these invasions, are for the most part descended from the original inhabitants, who were shorter.

Montessori (1905), who studied the anthropological characteristics of the women of Latium, came to the conclusion they belong to two types, differing so widely that they appear to spring from different races: one dolichocephalic, dark and short, and more frequently seen than the other, which is tall, brachycephalic and fair.

Of course besides the representatives of these two extreme types there are many persons whose characteristics are mixed (who have chestnut hair, eyes of a darker or lighter shade of brown, and who are mesocephalic and of medium height) because their parents belong to different races. Boas considers that variations in morphological characteristics may be brought about not only by sexual mixture, but also by change of abode. He published recently (1911) an account of the returns of a commission formed in Washington in 1907 for the purpose of studying the conditions of immigrants into the United States, and also the physical changes found in the descendants of immigrants. He studied various physical characteristics (height, length and width of the skull and head, relative cephalic index and facial width) in two types of immigrants, Jews from Eastern Europe, whom he regards as typical representatives of a brachycephalic people, and Sicilians, who are purely dolichocephalic. He extended this comparative analysis to the parent immigrants, their children born during the first few years of their residence in America and ten years later, and the children born in Europe. The result of these investigations, which proves that environment is a factor capable of modifying to a remarkable degree the characteristics of the human form, is as follows: the Jew tends to become taller, his brachycephalic head and broad face to become narrower—to approximate, that is, to the dolichocephalic, narrow-faced type.

In Sicilians, on the contrary, the dolichocephalic type shows a tendency to approximate to the brachycephalic form, by becoming wider in the face. Thus the two extreme types tend towards a single type, *i.e.* the one prevalent amongst Americans of the present day. The causes of this change must be sought in the environment.

These results are undoubtedly of the very greatest importance, since they solve one of the most difficult problems of anthropology, namely, that relating to the influence of environment on human types. Serious objections have, however, been made to the conclusions arrived at by Boas. Sergi (1912) brings two charges of inaccuracy against his work: the first against his method of investigation, which, being based on the comparison of average measurements, does not take into account the special characteristics of the different series; the second to the fact that the existence of a single type characteristic of North Americans has never been proved.

III. If we would give a brief summary of the scanty records of a physiological order relating to the different human races, we must first of all call to mind the variations which have been noted in the functions of vegetative life, doing so in the order which we have followed throughout the present work.

There is an ancient belief that the blood of tropical races is

darker than that of those inhabiting temperate climates and that the blood of northern peoples is lighter; Ranke, however, states that this belief is not borne out by scientific research and is probably based merely on the fact that the skin of peoples inhabiting the tropics contains more colouring matter than that of northern races.

The number of *red corpuscles* varies but little; in Europeans they number (as we saw in Vol. I.) 5 millions per c.mm.; in Indians and negroes, $4\frac{1}{2}$ millions; in Tierra del Fuegians, $5\frac{1}{2}$ millions (Maurel, Hyades, Deniker). Eijkman finds no great difference in the specific gravity or in the proportion of water and haemoglobin in the blood of the natives of tropical climates as compared with that of Europeans living either in the tropics or at home.

The frequency of the *cardiac pulsations* varies considerably more. We must bear in mind that Ranke considers Quételet's law that the frequency of the pulse diminishes in proportion to the increase in the size of the body has been proved to be inaccurate by the examination made by Gould and Baxter of the soldiers of North America belonging to all the different races inhabiting that continent.

We know that on an average the rate of the pulse of Europeans is 71 to 72 a minute (Vierordt); the rate in Tierra del Fuegians and the Tarantchis of Chinese Turkestan is the same—72 and 72·9 respectively (Hyades and Deniker); that of the white and negro populations of the United States is higher, 74·8 and 74 respectively; higher still is that of Indians and mulattos, 76·3 and 76·9, of the same country (Gould); the Torgutis, 76·6, the Kirghizis, 77·7 (Ivanowsky). Eijkman finds no great difference in the frequency of the pulse in the inhabitants of the tropics and Europeans.

The frequency of the *respiratory movements* does not vary to any great extent in the different races. The examination made by Hutchinson of 2000 English adults showed that the number of these movements ranged between 16 and 24 per minute, 20 being the commonest rate. Extreme cases, of very rare occurrence, showed a minimum of 9 and a maximum of 40 per minute.

Quételet found that the number of respiratory movements per minute in Belgians varied according to age; the figures are as follows: Infant, 44; child five years of age, 26; 15 to 20 years, 20; 20 to 25 years, 18·7; 25 to 30 years, 16; 30 to 35 years, 18·1.

Hyades, Deniker, and Ivanowsky state the frequency of the respiratory movements to be between 16 and 20 in Tierra del Fuegians; from 18 to 26 in Torgut Mongolians; 19 in Kirghiz; 18 in Afghans.

The data collected by Gould and Baxter in their military statistics give us the following figures relating to North Americans:

Race.	Number of Soldiers examined.	Average Height.	Average Rate of Respiration.	Average Circumference of the Thorax at the level of the Nipple.	Average Expansion of the Thorax or difference in the circumference between Inspiration and Expiration.
		Metre.		Metre.	Metre.
Indian	121	1.72	15.8	0.86	0.07
White	315,620	1.71	16.4	0.84	0.07
Negro and Mulatto	25,828	1.68	17.7	0.85	0.065
			19.0		

According to what we saw in Vol. I. p. 423, the vital capacity of the German is 3222 cubic cm., that of the English 3772. Deniker states that it varies in European races from 3000 to 4000 c.c. Gould gives the following figures applying to North Americans:

Race.	Number of Persons examined.	Average Height.	Average Vital Capacity.
Indian . . .	504	1.73 metre.	3033 c.c.
White . . .	15,124	1.70 "	3009 "
Negro . . .	1,631	1.68 "	2709 "
Mulatto . . .	671	1.68 "	2649 "

Eijkman says that there is no difference between the frequency of the respiratory movements in Europeans and the inhabitants of the tropics.

We possess a relatively large number of data relating to the *strength* and *muscular work* of the different races.

Ranke points out that the average statistical data at our disposal do not bear out the assertion, which has been made more than once, that the muscular strength of Europeans is superior to that of other races.

Two methods were adopted for measuring work and muscular strength: the first by calculating the maximum resistance to work, such as marching, lifting weights, etc., and thence reckoning the maximum production of the given work; the other by making use of ordinary dynamometers, by means of which it is possible to measure the maximum effort of which any given contracting muscle or group of muscles is capable.

Of the results obtained by the former method, we will first refer to those of Coulomb, who noticed that French soldiers employed on levelling work in France and Martinique (lat. 26°) accomplished at the very outside half the amount of work in the latter place. Other observations tend to show that Europeans are unable to accomplish the same amount of work in the tropics as they do at home. On the other hand we have instances of the

contrary : Nachtigall's accounts of his marvellous journeys in the Sudan, which were accomplished partly on foot, laden with his gun and other impedimenta, afford clear evidence that the European does not necessarily lose his capacity for hard work when in a tropical climate. On several occasions marches of ten hours a day were made, involving work corresponding to 300,000 kilogrammetres (Ranke).

If it be open to question whether the capacity of Europeans for work remains unaltered in tropical climates, it is an undoubted fact that the natives of such climates are capable of doing a remarkable amount of work. Their walking powers, as recorded by reliable explorers, are extraordinary. Amongst the Peruvian Indians the so-called post-boys, who do all their journeys on foot, walk twenty leagues or more in a day (134 kilometres).

Nuttal says that the Ossagis of North America walk sixty English miles (96 kilometres) a day, and Roger Williams that the Indians of New Britain can accomplish 128 to 160 kilometres a day. Darwin tells us that the natives of Tahiti can walk the whole day carrying a load of 45·4 kilos on either side, which, taking a march of eight hours at an average rate of walking, would, according to Ranke, amount to the production of work equivalent to 330,000 kilogrammetres.

Darwin says that the Apiri, who work in the mines of Chili, bring to the surface daily from a depth of 73 metres a load weighing over 91 kilos. Ranke calculates this daily production of work to be equivalent to 157,077 kilogrammetres, whereas the daily work of European miners only amounts to 128,000 to 131,000.

The capacity of representatives of various races has been determined by means of dynamometers. Weisbach measured with the manual dynamometer the strength of the pressure exercised by the hands of a large number of natives, more especially Asiatics and Australians.

The Polynesians are the strongest of all, next to them come Australians, Malays, and Chinese. His figures are as follows: New Zealanders, 68·2 kgrms.; natives of Stewart Island, 56·44 kgrms.; Bugic, 50·23; Amboinese, 48·69; Nicobarians, 48·4; Sudanese, 46·76; Australians, 46·36; Javanese, 44·25; Chinese, 42·28; Maduresians, 30·27.

The same order holds good for the women; the women of Tahiti are the strongest, 34·21 kgrms.; Australian women, 25·86; Javanese, 22·53; Sudanese, 21·34; the weakest being the Chinese women, 21·04.

Whilst these average results are of a certain comparative value, since they were all obtained in the same way, we must not attach too much importance to them, seeing that the number of persons examined is relatively small (Ranke).

Gould's careful and extended study of the soldiers of North

America, made at the time of the Civil War, is of considerably greater value. He confined himself to testing the strength of the hips by Quételet's method; in other words, the force exercised in raising the trunk erect on the loins, measured by means of a special dynamometer. The results are shown in the following table:

Race.	Number of Persons examined.	Average Lumbar Force in kgs.
White	13,406	144·4
Negro	1,600	146·7
Mulatto	704	158·3
Indian	503	159·2

From these figures it would appear that the coloured races are stronger than the white Americans. The proportion changes, however, when the original occupation and home of the white soldiers is taken into consideration; thus the lumbar force of the white soldiers belonging to the second series of measurements, who were for the most part farmers and working men from the northern states, averaged 155·7 kgrms., the number measured being 6381.

Quételet's measurements of Belgians show that the strength of the hips increases with age (just as does that of the hands) from earliest youth till from 25 to 30 years of age, when it reaches its highest point, after which it slowly declines.

Gould's measurements showed that the white American soldier was at his strongest at 31 years old, and that no change took place during the following three years; this holds good of negroes and mulattos also. The Iroque Indians, on the contrary, attain their maximum lumbar strength after their thirty-fourth year, between 35 and 44 years of age.

IV. One of the characteristics which varies most amongst different races, and even amongst different tribes of the same race, is *language*, or the nature of the means used by social man in order to communicate his sentiments, thoughts, and wishes to his fellow-men. Some modern ethnologists, Deniker and Vierkandt amongst others, judge the stage of civilisation reached by different races by these linguistic characteristics, classifying the various races as follows:

(a) *Uncivilised races*, who have no written language but sometimes make use of pictography. These are further subdivided into two classes: (1) *hunters* (Bushmen, Australians, Tierra del Fuegians); (2) *agriculturists* (North American Indians, Melanesians and most negro peoples).

(b) *Semi-civilised races*, who make use of ideographic, and even phonetic writing, but whose literature is rudimentary. These may be subdivided into two groups: (1) *agriculturists* (Chinese,

Siamese, Abyssinians, Malays, Peruvians, and the ancient Egyptians); (2) *nomads* (Mongolians, Arabs).

(c) *Civilised* races, who have a more or less phonetic written language and abundance of literature (Europeans and North Americans, etc.). We do not propose to go deeply into the interesting study of ethnical linguistics, but merely to touch on the more important points which are of interest to the physiologist.

We would first point out that language is not the only means by which men can understand each other and interchange ideas. Deniker divides the means by which man attains this end into three groups: (a) means of communication at a short distance (*gestures* and *words*, *mimic* and *phonetic language*); (b) at a relatively great distance (*signals*); (c) means serving for the communication of thought, irrespective of the limitations of time and space (*writing*).

Many gestures are natural and common to all; every one understands them because they are identical with the movements made in the processes to be expressed thereby (gestures indicating eating, drinking, etc.). Other gestures—both more important and more varied—are real conventional *symbolical motions*, indicating special psychic conditions, and are therefore only understood by those who have attached that meaning to them.

The simplest and commonest sign of this kind is that made with the head to express affirmation or negation. It is, however, a fact that different peoples attach opposite meanings to this sign; Northern and Central Europeans, the inhabitants of the Adaman Islands, the Ainus and some Hindus, nod the head to express affirmation and shake it to express negation; amongst other peoples—Arabs, Botocudis, negroes—shaking the head is a sign of affirmation, and raising it that of negation; Abyssinians and Neapolitans raise the head and eyebrows as a sign of negation, whilst the Syrian Arabs and the people of Noya-Kurumba express the same meaning by raising the head and clicking the tongue. Italians and other Mediterranean peoples express negation and many other psychical conditions by means of movements of the upper limbs. This use of gesticulation with the head, upper limbs, or whole body in order to express different psychical conditions or to give added force to their verbal expression is not peculiar to these races; Mallery considers that the language of signs has attained its highest development amongst the North American Indians (a race which is unfortunately dying out rapidly, owing to the influence of the whites and their civilisation), where it may be compared to that used by deaf-mutes who have not learned the lip-language. At the time when this language was most in use, the Indians expressed by its help, not merely common and proper nouns, but also verbs, pronouns, and other

parts of speech. By combining gestures of the body, head, and arms, they made long speeches, even making use of abbreviations, just as in pictographic writing.

We have no desire to encroach upon the domain of comparative philology, and will therefore merely point out that the numberless dialects and tongues spoken by man fall into three fundamental linguistic groups, according to their structural characteristics: (a) *monosyllabic* or *isolant*; (b) *agglutinant*; (c) *inflected*.

In monosyllabic languages (peculiar to the Chinese, Indo-Chinese, and Thibetan) each word is invariable; there are neither declensions nor conjugations, and the relative meaning of a word depends upon its position in the sentence. Since there are many homophonous words having different meanings, they are distinguished from one another by the way in which they are pronounced or by their pitch.

In agglutinant languages, which are those most commonly spoken, the words are formed of several elements put together of which one alone has a specific value of its own, whilst the others merely serve to define it more closely, and have therefore a purely relative meaning. The fundamental element is the so-called *root*, the others are termed *affixes* (*prefixes* or *suffixes*, according to whether they precede or follow the root), and are usually roots which have become obsolete, have lost their original meaning, and are only used as determinative particles.

The difference between the *inflected* languages (spoken by Indo-Europeans) and those belonging to the agglutinant group lies in the fact that in the former the root may be modified in order to express special relations existing between it and other roots. Sometimes the prefix or suffix undergoes this change, or inflection, instead of the root.

No less interesting is the study of the means devised by different races for the communication of their ideas and psychical and physiological conditions at a distance of space and time.

We will not dwell upon the signals used by various primitive races to communicate with one another beyond the range of the human voice, but will confine our attention to some of the more important points connected with the chief means of communication irrespective of space and time, writing, or the graphic symbolic representation of the spoken language.

Writing, as the symbolic representation of words (alphabetical writing), may be regarded as a recent acquisition of civilised nations. It was in all probability preceded by another non-symbolical form of representation, the direct graphic representation of things and objects, the so-called *ideographic* or *pictographic* writing which is in use to this day amongst some of the lower races.

Pictography probably gave birth to the figurative hieroglyphic

and hieratic writing of the ancient Egyptians, from which the Phœnician alphabet—the source of all our European writing—was derived. Some philologists, F. Müller and Trombetti amongst others, consider the fundamental characteristic of the languages spoken by man to be of such importance, that they base on them their classification and derivation of the different human races. Investigations of a more profound order, however, show this hypothesis to be untenable.

Von Luschan (1911) rightly observed that oneness of language does not always involve oneness of race. Meinhof, who studied all the dialects spoken by the peoples of Northern and Central Africa, proved that all these dialects, which appear different, really belong to one and the same language, Bantu, from which they are derived by simple phonetic changes. Morphological, ethnological, and historical research all prove that the inhabitants of this vast tract of country belong to different races, which have become mixed during various immigrations. Von Luschan, who is at one with Lepsius on this point, notes that in every immigration of foreign races the immigrants are very few in number, in comparison to the old inhabitants of the country.

“They have burnt their boats behind them, they have no Hinterland of race akin to their own, they have few or no women with them, and they are not acclimatised like the older inhabitants. Hence the further they are from their native land, the smaller their number in comparison with that of the natives, the fewer the women they have brought with them, and the more unfavourable the influence of the new climate, the more quickly will they become fused with the original population as regards their physical characteristics. When, however, we come to consider their psychical qualities, the case is reversed; language, grammar, religion, and everything related to anything written develops independently of the numerical relation existing between the immigrants and the old population; the decisive factor is ability and absolute superiority. The victory will be won by the more highly developed language, the more perfect grammar, the more advanced religion, and better writing, wherever there is any question of these things.”

We see then that a change of civilisation brought about by the immigration of another people does not always involve a great alteration in the anthropological characteristics of the original people, race, or nation.

There is but little to say with regard to the functions of the central and peripheral *nervous systems* in their entirety, owing to the scarcity of reliable data on this subject. The information afforded us by different explorers as to the psychical faculties of various representatives of the human race is undoubtedly of value, but obviously belongs rather to the realm of psychology.

Gryus recorded the reaction time to auditory excitation in the natives of Java and in Europeans resident in that island. He found that this period was shorter in the case of natives and became longer and longer in Europeans; that is, the reaction time increased in proportion to the length of their residence in the tropics. Kohlbrugge regards this as a proof that a tropical climate is injurious to the functions of the nervous system of Europeans. This Dutch scientist, who bases his conclusions on empirical data collected in his native country during three centuries of colonisation in tropical Asiatic islands, considers the climate of the tropics to be ill-suited to Europeans, who after a prolonged residence in such climates suffer from disturbances of the nervous system, such as insomnia, irritability, inability to perform intellectual work, debility, and neurasthenia. The data at our disposal relating to the efficiency of the various *organs of sense* are relatively numerous; unfortunately, however, very little of this research work has been done from the physiological point of view or with the accurate instruments used by the physiologist. We will mention a few of the more important conclusions.

Owing to the glowing accounts given by various explorers of the activity of the organs of sense, and more especially of sight and hearing, possessed by certain primitive peoples, scientists came to believe that these races were really endowed with organs of sense of a higher order than those usually found in civilised nations. Deniker states that the inhabitants of the Andaman Islands can find certain kinds of fruit growing in forests at a considerable distance solely with the help of the sense of smell.

Kotelman (1884) says that the acuteness of normal sight, measured by Snellen's method, increases in different races at the rate shown in the following table:

Germans	1.1
Russians	1.4
Georgians	1.6
Ossetis and Calmucks	2.7
Beggia-Nubians	3
Andes Indians	5

The sharpest sight was found in a Calmuck, 6-7.

Recent and more accurate investigation tends, however, to prove that there is no great difference in the acuteness of the organs of sense in different races, a fact already noted by Fritsch (1872) in the case of the natives of South Africa.

Rivers (1905) made an accurate study of the organs of sense of the Todas, determining in the case of the eye, sharpness of sight, chromatic vision, and optical illusions; in taste, the threshold of the four elementary tastes; in the ear, sharpness of hearing; in the nose, the acuteness of smell; in the cutaneous senses the discriminative tactile threshold and the threshold of

sensibility to pain. On the whole he found no essential difference between Todas and English, with the exception that colour-blindness is much commoner amongst Todas and they are far less sensitive to pain.

Ranke, who made accurate tests of the sharpness of sight of South American Indians, found their sight to be no better than that of Europeans.

Pechuel-Loesche (1907), who tested the sight, smell, hearing, taste, and sensitiveness to pain of the Africans on the Loango coast, came to the same conclusions as Rivers, finding no great difference except in sensitiveness to pain, which appears to be duller in these races than in civilised nations.

Rivers rightly observes with regard to this point that the comparison usually made between the sensitiveness to pain of the lower races and that of civilised nations is not absolutely reliable, since in the latter case the individuals tested lead a life too dissimilar to that of the former; we ought rather to compare data obtained by examining our peasants, whose life in many respects resembles that of these lower races.

That the sense of hearing possesses the same fundamental properties in all human races seems to me to be proved by Baglioni's examination (made in 1910) of various musical instruments, some belonging to different African tribes and others to natives of Oceania and America. He tested the musical pitch of the sounds produced by these instruments, more especially by African instruments of percussion (marimbas and sansis) and wind instruments (Pan's pipes) and the musical intervals between the single notes, and found that some of them had an almost perfect classic, diatonic scale—the scale, that is to say, on which the music of all civilised races is based—and that in all of them intermediate degrees could be produced leading more or less directly to the full realisation of the musical scale, based on the principle of harmonically consonant intervals (octave, fifth, major, and minor third). Hence the diatonic scale cannot be regarded either as the fruit of our artistic culture or as resulting from the special exigencies of certain musical instruments, as is held by Wallaschek. It is rather the natural and direct result of the demands made from within, otherwise of the psycho-physical properties with which the sense of hearing of the whole human race is endowed. This does not, however, prevent the music of certain races possessing special characteristics, due to preference for certain musical intervals. We know, for example, that Greek music reached an advanced stage of development in the melodic mode, in which, as well as our diatonic and chromatic scales, an enharmonic scale was used, having intervals smaller than a semitone and quite unknown in modern music (Gervaert). Stumpf (1901) proved that the Siamese make use of a special

scale having seven equal intervals, which Baglioni (1911) found

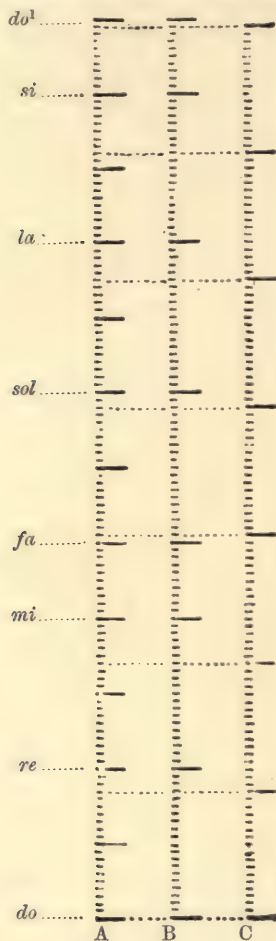


FIG. 134.—Diagram showing the two European scales, (A) tempered, (B) diatonic, as compared with the oriental scale (C). The intervals of a tempered semitone are divided into ten fractions (tenths of a semitone); the interval between each sound in the oriental scale corresponds to about seventeen of these fractions. The consonant intervals in the oriental scale are all more or less altered, the only exception being the octave. The fifth is about two-tenths lower, the fourth one-tenth higher, whilst the two thirds are fused into a single neutral third midway between the major and minor third. (Baglioni.)

to be common to all eastern Asiatics (Chinese, Japanese, Burmese, Indians, and Syrians). This tempered eptatonic scale differs from our tempered diatonic scale, but has in common with it the advantage of being readily transposed (Fig. 134).

These results show the utility of investigations into acoustics and comparative musicology as signs of the affinity or relationship existing between the civilisation of different peoples, more especially if the absolute pitch of the notes in use be taken into account (von Hornbostel).

Undoubtedly, one of the most important chapters in physiology is that relating to the *functions of the organism as a whole*, to alimentation, and more especially to the exchange both of matter and energy which is a direct consequence thereof. Seeing what a great influence is exercised by external temperature on the exchange of material and the production of heat in the human organism, we shall readily understand that great differences exist in these respects between races inhabiting different climates. Theoretically, indeed, we should expect to find a smaller quantity of nourishment required by the man living in the tropics than is needed by the inhabitant of the polar regions if he is to cover his loss of heat. There are, however, two other facts which have a contrary effect and tend therefore to lessen this

difference: the greater quantity of heat employed in the evaporation of a larger quantity of water from the surface of the body and

lungs, which mitigates the excessive heat of the environment in the inhabitants of hot climates, and the wearing of clothes and furs by the natives of cold climates in order to lessen the loss of heat.

Whereas life in hot climates, says Ranke, is so arranged as to facilitate as much as possible the emission of heat from the surface of the body by means of absence or lightness of clothing, free ventilation, and cold baths, the natives of cold countries protect themselves against loss of heat by every means in their power.

Ranke, basing his remarks on the result of his own research work and on the information afforded him by explorers conversant with the alimentation of different races, points out the error of the statement so often made that the exchange of material, or, to put it better, the general need of oxidation in people living in hot climates, is much less than in people inhabiting cold or temperate climates. It seems to me, however, that the investigations which have hitherto been made tend to show that a difference, albeit a small one, does exist.

With reference to the inhabitants of hot climates we will take the results of the examination made by Glogner in 1889 of European soldiers who had lived for some time in the tropical climate of Sumatra. He found a smaller consumption of protein in those Europeans who had lived for any length of time in that country and might therefore be considered acclimatised. Soldiers who had spent less than four years there eliminated on an average 0.143 gm. of nitrogen for every kilogramme of body-weight, against 0.101 gm. in the case of those who had been there more than four years, a figure closely approaching that observed by Chittenden in economic proteid nutrition (page 97 and following pages of this volume).

Lehmann, on the contrary, found that the quantity of sodium chloride eliminated in the urine of the individuals examined by Glogner was the same as in Europe—that is, on an average 15.65 grms. in twenty-four hours.

In 1889 Glogner began his first calorimetrical examinations of twenty European and twenty Malay soldiers with the object of establishing the amount of heat lost by the skin of the forearm. For this purpose he made use of a water-calorimeter. He found that the dark skin of the Malays emitted heat more easily than the fair skin of the European, since the Malay skin lost 10.5 units of heat to the square centimetre in half an hour and the European skin only 8.7. Glogner calculated that a European, having a bodily superficies of 15,000 square centimetres, would yield 6,255,000 units of heat to water at 28° C. in which he was immersed, supposing, that is, the same capacity for emission to exist all over the body, as against 7,560,000 units yielded by a Malay (a difference of 1,305,000).

The same writer made another set of investigations in order to find the amount of heat emitted by the inner cutaneous surface of the thigh; for these experiments he made use of the Winternitz air-calorimeter. He found that on an average the temperature of 60 c.c. of air is raised 1.4°C . in ten minutes by the white skin of a healthy person, the temperature of whose body is 37.2°C ., whereas it is raised 1.7°C . by the brown skin of natives under exactly the same conditions; so that the skin of the native emits a greater amount of heat than does that of the European, and we therefore see that in hot climates Europeans are at a considerable disadvantage as compared with natives.

According to Glogner, another point in which Europeans living in the tropics differ from natives is the course of the curve of the temperature of the body in the twenty-four hours; in the Javanese this curve shows oscillations much like those of the curve of the temperature of the body of Europeans living in Europe (see results of Jürgensen and Liebermeister, page 67 of this volume), but the curve of the temperature of Europeans living in the tropics takes a different course. We note that during the early morning hours it rises earlier and more rapidly; during the day it remains relatively stationary, so that between 7 and 9 A.M. the temperature of the body is about half a degree higher than in Europe at the same time. It is not however accurate to say—as is stated in various books on the subject—that the temperature of the body in the tropics is on an average half a degree higher than in Europe, since later in the day, when the temperature rises in Europe, it remains stationary in the tropics, as we have already pointed out.

Glogner further remarks that in the tropics the tissues of men and animals, European and native alike, contain less fat, and therefore the inhabitants of such climates show less tendency to grow fat than those of cold or temperate climates. He thinks that this tendency may be explained as one result of acclimatisation—that is to say, as an adaptation to the special need in hot climates of eliminating the greatest possible amount of heat from the body, which end is attained by reducing the thickness of the subcutaneous adipose layers. This process is the exact opposite of that which is observed in organisms living in cold climates.

All explorers agree that the inhabitants of cold climates, such as the Eskimos, can consume, and indeed require, an enormous amount of fat-containing food. The observations made by the famous explorer Nordenskjöld during the winter spent by him and the crew of the *Vega* in Bering Straits show that Europeans living in these severe climates also need a richer diet if they are to remain in good health. The men's rations contained a larger quantity of proteins and fat than would be required by a well-fed

workman in our own climate, and double the minimum amount of carbohydrates necessary in temperate climates (Ranke). Food is the best protection against cold, says J. König.

Ranke remarks, however, that the data at present at our disposal do not suffice to prove the exchange of material of northern peoples to be of absolutely greater value than that of peoples living in milder climates. It is an undoubted fact that the inhabitants of the Arctic regions eat a great deal (and more especially a large quantity of fat), so long as they have plenty; but as they have no idea of provision for the future they have to endure times of absolute want, specially in winter. We do not know whether the crew of the *Vega* really consumed the large quantities of food dealt out to them; in Nordenskjöld's story there are constant references to remains of meals being given to Teiucci beggars.

The data at our disposal are too scanty and too contradictory to afford a definite solution of this important problem of the influence of climate on metabolism in man. Eijkman, who studied in Java the metabolism of natives and Europeans, considers that there is but little difference between the two races. He was surprised to find that the production of heat or process of oxidation was slightly greater in natives than in European immigrants of the same weight. He found that there was a difference in the quantity of water discharged by the kidneys and by perspiration, but he ascribes this fact to the difference in the quantity of liquid drunk by the two races. Negroes in the tropics perspire much less than Europeans, though Kohlbrugge found the number of sweat-glands in their skin to be the same as in white people. The capacity of negroes for reacting to heat with much less secretion of sweat than Europeans—that is, without suffering from constant cutaneous hyperaemia, which may give rise to skin diseases, such as dermatitis, epidermitis, intertrigo, etc.—is by no means an unimportant factor in their adaptation to their native climate. On the other hand, the fact that in tropical climates the white man is constantly perspiring makes the horny stratum of the skin, which is saturated with water, become thicker and more opaque, and thus, in Kohlbrugge's opinion, causes the pallor so often noticeable in Europeans living in the tropics. This pallor is not, as has often been supposed, a sign of anæmia, but is due to the fact that the blood-vessels are not so visible owing to the altered state of the skin. The dark colouring-matter in the skin of negroes prevents this pallor being noticeable in their case.

The Melbourne physiologist, W. A. Osborne, studied in himself and an Australian boy of fourteen the loss of water through the skin and the lungs, the amount of air exhaled, the amount of carbon dioxide eliminated and the respiratory quotient,

in varying conditions—rest, walking, work in the shade. He recorded the external temperature (which varied from 39.4° to 17° C.), the moisture, and wind—all the experiments being carried on in the open air, and between January and April, the hottest months in those regions. The results of the experiments partly confirmed and partly contradicted existing ideas. He found that the loss of water by the skin through evaporation, whilst in direct proportion to the outer temperature, depends not only on this factor, but also on the dampness of the air. If the temperature remains unchanged, but the relative humidity of the air is diminished, the loss of water by the body will of course increase. The same thing happens when the air is stirred by wind, hence a strong, cold, dry wind causes a notable increase in the amount of heat lost by the body, which can only be met by an increase in its metabolism.

He confirms another fact already noted, namely, the great increase in pulmonary ventilation when the external temperature rises. Osborne ascribes this thermic hyperpnoea or polypnoea to the heating of the carotid blood in its passage to the head.

In contradiction to the way in which homothermic animals react, he remarked that the quantity of carbon dioxide exhaled was in direct, not inverse, proportion to the outer temperature. This agrees with the results arrived at already by Voit and Rubner, and is in all probability partly due to the increased work performed by the respiratory muscles.

In conclusion, it would appear that with the increase of the external temperature the respiratory quotient increases also and approaches unity. This harmonises with the results obtained by H. Sutton in his laboratory researches in 1908, which led him to conclude that this special reaction of the inhabitants of tropical countries depended upon the preponderance of carbohydrates in the diet of these peoples.

W. P. Chamberlain, who, in 1911, studied the influence of the climate of the Philippine Islands on a large number of both white and coloured soldiers, came to the conclusion that it is impossible to establish any invariable difference in the health of the two types. He considers it extremely doubtful whether the action of the solar rays is a factor to which the injurious influence of tropical climates can be ascribed.

Another question in close connection with the exchange of material is that of dress. It might logically be supposed that its adoption first began when man left his original habitations, which were probably in some warm country, and took up his abode in colder climates, where the necessity of lessening the loss of heat as far as possible made him cover himself with garments or furs.

This supposition is undoubtedly a very plausible one; ethnologists have, however, pointed out that by no means all races

living in cold climates have learnt to protect themselves against the loss of heat by means of clothes. The famous ethnologist, F. Ratzel, tells us that the comparison of races living in a state of nature in cold countries and the inhabitants of the temperate zones does but show how seldom necessity—that greatest of teachers—has succeeded in making these primitive peoples understand how to counteract the effects of their unfavourable environment. The inhabitants of the east coast of Tierra del Fuego wear cloaks of lama skins, and those of the west coast seal skins, whereas the tribes of Wollaston Island wear no other protection against an equally cold climate than the skin of beaver or some other small animal, about the size of a pocket-handkerchief, which they fasten across the chest with straps, and many do not even wear this very primitive garment. Darwin saw inhabitants of Tierra del Fuego in canoes—a woman amongst them—who were absolutely naked. It was raining fast, and they were drenched with the rain and the water dashed up by the oars. Ethnologists consider that the use of clothes originated more for the gratification of psychic requirements or tendencies than for protection against cold, and more from a desire to adorn the body (an aesthetic sense found everywhere and deeply rooted in human nature) than from the desire to conceal the sexual organs (a sense of modesty).

We now pass on to the consideration of the *means of nutrition* used by the human race in various countries. As we have already seen in Chapter III. of this volume, man may be regarded as *omnivorous*; and the more we consider the various substances eaten by different races the more applicable does this adjective appear.

C. Letourneau (1880) considers that man began by being frugivorous; he became omnivorous as soon as he learnt the use of fire and how to cook his food. In our day, when man is cosmopolitan, the savage is frugivorous in the tropics, and tends to become carnivorous the farther north he goes. Even in the Arctic regions, however, the liking for vegetable food does not disappear, for we find that the Eskimo regards the undigested vegetable food found in the stomach of the reindeer as a great delicacy.

Whilst the Hottentots and Bush peoples devour animals which have only just been killed, and are sometimes even still alive, without cooking them, many other uncivilised peoples are in the habit of cooking their food. This habit has developed gradually amongst different races quite independently of one another, as is seen by the widespread use of pots and pans.

The art of bread-making, for instance, the greatest of all culinary inventions, arose independently in different parts of the world; some races to whom agriculture is still unknown yet make

bread, amongst others the Tahitians and Polynesians, whose flour is made of wild fruits (Letourneau).

The difficulty which man encounters in supplying himself with food is of course much greater in some parts of the globe than in others; only in the tropics does he find enough nutritious plants and game to provide for his wants without any trouble on his part; when therefore he found his way from the tropical to the temperate or frigid zones, and had destroyed a large amount of the game which abounded in those far-off days in the forests, had fished and gathered the wild fruits, he soon began to feel the need of a more rational system, and took to agriculture and the breeding of cattle, which ethnologists agree in considering the basis of all higher civilisation.

We may here point out that there are still certain Australian races, living in regions rich in food-stuffs, who are quite unacquainted with both agriculture and cattle-breeding. Others, the Hottentots for instance, are first-rate cattle-breeders but quite ignorant of agriculture.

In addition to what we have already said on page 44 as to the need felt by certain African negro races of mixing salt with their food, we may call to mind R. Pöch's remarks on the Melanesians of New Guinea. He found that the natives of British New Guinea, who live mainly on a vegetable diet, use the salt which they extract from sea-water. They not only cook their food in salt water, but evaporate the water in receptacles in which they place pieces of porous wood which become impregnated with salt and are then regarded as articles of commerce.

The inland tribes come down to the coast to get sea-salt; amongst these tribes rock-salt is the most coveted article of commerce. On the other hand, the natives of Dutch New Guinea never use salt and have no word for it in their language. They inhabit a region where game is abundant and, being skilful hunters and fishermen, live mainly on animal food. This agrees with Bunge's theory that the need for salt in the food depends upon the diet.

We cannot close our remarks on the nutrition of the human race without alluding to a special kind of animal food eaten by certain savage races which has always called forth feelings of horror and disgust amongst civilised peoples—*Cannibalism*, that outrage on humanity, which is not, however, so widespread as is commonly supposed. Bergmann (1893), who made a special and thorough study of existing records of the subject, considers that in our day cannibalism is practised by the races of Oceania, central Africa, and South America. The Battas of Sumatra, the natives of the Solomon Islands, of New Britain, and of certain islands in the New Hebrides are incorrigible cannibals. The other inhabitants of Oceania are gradually abandoning it. In

South America the Arovachis, certain Columbian Indians, the Botocudis, and some other Brazilian tribes are undoubtedly addicted to cannibalism, but it is most prevalent in central Africa. It appears to be unknown to races living either above or below the twelfth degree of latitude. Deniker and other ethnologists tell us that cannibalism is practised for three reasons: necessity, gluttony, and superstition.

Cannibalism in the first of these cases is caused by a lack of animal food (Australia), or by special circumstances, such as shipwreck or famine, when it has been known to occur even amongst half-civilised races. This kind of cannibalism is, however, very rare, as is also that induced by gluttony. It is, however, related that the Melanesians of the Solomon Islands and the New Hebrides hunt man solely for the sake of the pleasure of eating human flesh. The Niam-Niams (Africa) hunt man not only for the sake of his flesh, but for the human fat which they use in various ways.

Certain Ubangi tribes and the Mangema (Africa) buy slaves or capture men on purpose to fatten and then eat them; sometimes they steep the bodies in water so as to improve the flavour.

With these two kinds of cannibalism must be classed the custom of eating old people and children, killed in order to diminish the number in the family (Australians).

Ritual anthropophagy, based on superstitious beliefs, such as that superior physical or intellectual qualities could be obtained by consuming part or the whole of a person possessing such gifts, seems to be the commonest of all. It is related to the custom of offering *human sacrifices*, which occurs even amongst relatively civilised races. Pösch says that the natives of British New Guinea and of the adjacent islands seldom devour the whole body of their enemy, but usually confine themselves to eating the brain and tongue with a view to inheriting his psychic qualities. The Kaja-Kajas of Dutch New Guinea hunt their foes for the sake of the head only. In some islands, however, cannibalism is at all events partly caused by want of food.

VI. Having now dwelt upon the structural and functional characteristics distinguishing the existing human races, we will turn our attention to those of the races which preceded them. This is one of the most difficult and the most attractive of problems, since it is intimately bound up with that of the origin and evolution of civilised nations. The biologist considers it to be an incontrovertible fact that we have reached our present state of civilisation by slow degrees—by passing through a number of stages—and that our remote forefathers had a culture very inferior to our own. The historic documents which have come down to us from the earliest civilised peoples (Babylonians,

Egyptians, Greeks, and Romans) and from the Middle Ages prove by what a slow and gradual process of evolution the civilised nations of Europe have attained their present development—a process which may be compared to the slow evolution through which the different animal and vegetable types succeeded one another and were modified or transformed on the surface of the earth during the long geological periods. Of course this slow progress sometimes suffered checks and reverses, as, for example, the temporary destruction of Greek and Roman civilisation by the barbarians. If we would solve the problem of the origin and development of man we must have recourse to the same source as the zoologist and botanist who would reconstruct the genealogical tree of animal or vegetable types: we must study the remains of individuals of the same type which are preserved in the different geological strata. We are indebted to *palaeontology* for the most interesting and reliable records of man, as of every other organism. As is well known, these fossil remains are those of different parts of the skeleton, the structure of which allowed of their preservation in the different strata. We do not possess a sufficiently large collection of these fossil human remains to enable us to reconstruct his genealogical tree with absolute accuracy; the scanty remains, however, which have been brought to light during the last few decades testify to the existence of the human race in a long distant past; they are tangible evidence of lower forms who once lived and have now become extinct, links between our anthropoid ancestors and man as he is to-day.

We will consider some of these remains in connection with the question of the *origin* of the human species.

The *geological period* in which man, as a form distinct from other animal forms, first made his appearance is still under discussion, because the discovery of fossilised human remains in petrographical strata whose geological age is certain is of comparatively rare occurrence. It is, however, certain that recent discoveries have proved the erroneousness of the view hitherto taken by most scientists that man appeared during the quaternary age (diluvial or glacial period). It is now an established fact that man made his appearance in an earlier age, in the last periods (miocene or pliocene) of the tertiary age (Rutot), when Europe had a sub-tropical climate, with the flora and fauna found to-day in hot countries.

Of the development of man from that remote age down to the periods of historic civilisation (Egyptian, Greek, Roman) we have no direct knowledge based upon historical documents or writings; it is the subject of pre-history (or *esostory*). The only foundation on which it can be reconstructed is the remains of these peoples found in their dwelling-places, and above all in their tombs. Only

during the last few decades has the study of these remains of pre-historic civilisation been undertaken, but it has already afforded us various important data enabling us to determine the different stages through which civilisation has passed before reaching its present development.

Another rich mine of documents enabling us to reconstruct the stage of civilisation at which our forefathers had arrived is afforded by the remains—many of them fossilised—of articles made by them. *Palethnology* is that branch of modern science which, taking these records as its basis, reconstructs from them the degree and aspects of these ancient civilisations. The fossil remains of human activity are naturally articles used as tools or instruments enabling the owner to obtain food, such as weapons, agricultural implements, culinary utensils, or articles of personal adornment, made of materials which would not wear out and could be preserved, such as stone, bone, metal, and earthenware. *Comparative ethnology*, or the study of the customs and culture of people living in our own day on the same level as the primitive races of Europe, using utensils and other articles to all intents and purposes the same, is of the greatest assistance in enabling us to understand these different stages of primitive, prehistoric, or proto-historic civilisation. The study of *ontogenetical* development, or the different stages of psychical development through which our children pass at different ages, will afford material which is by no means to be despised for the theoretical construction of the various stages of psychic activity which have led up to that at which we have now arrived.

We also have historical documents, the records which have come down to us since the invention and use of writing. This discovery, however, was made at a comparatively late period, so that the earliest written records reveal a very advanced stage of civilisation, such, for instance, as that of Greece.

We will glance briefly at the result of these researches, which make it possible to attempt to reconstruct the slow progress of humanity towards our present state of civilisation.

In order to form a judgment of the different degrees of civilisation we must take into consideration the various ways in which human activity has been displayed, more especially social and individual customs (organisation of the state and family); the diet adopted, and the means used for protection against inclement climates and for turning to account the brute forces of nature; the artistic productions and scientific or philosophic knowledge; the religious beliefs or superstitions, etc.; everything in fact appertaining to that practical, intellectual, and moral heritage which constitutes the wealth of nations, and distinguishes man from the rest of the animal world. We may study the origin and development of each of these elements—questions to which our

present information does not allow any but a fragmentary and partial answer.

As an example of a method of classifying the *different stages of prehistoric civilisations* and of the order in which they succeeded one another, we may take the one drawn up by M. Verworn. It is, as the author himself says, of merely relative value, since it refers to a science which is still elementary, and like every such classification the result of more or less arbitrary subdivisions, since it refers to a succession of facts and phenomena which develop slowly and gradually out of one another in a continuous series. It will, moreover, give a summary of the more common characteristics and of the order of the various civilisations and not of their chronology, which cannot be shown in any general scheme, since different stages of civilisation may exist at the same time in different parts of the world. For instance, last century there still existed in Tasmania a real archeolithic civilisation, and at the present time there exist races in the Polynesian Archipelago whose civilisation is that of the neolithic age. The indications of the geological ages given in the following scheme only hold good of European civilisations of which we know more. The primitive stage of so-called *colithic* civilisation (from the Greek *ῥῶς*—dawn) forms the subject of lively discussions at present. The existence of this stage, which, though not geologically proved, is affirmed by Rutot and Verworn, must be hypothetically granted, since we cannot but suppose that stone was used in its raw state before being worked in order to adapt it for use as culinary or agricultural implements or weapons, just as is done by certain monkeys in our own day, who use it sometimes, Schweinfurth tells us, to crack nuts.

SCHEME SHOWING THE DIFFERENT STAGES OF EUROPEAN PREHISTORIC
CIVILISATION.

Stage of Civilisation.	Essential Characteristics of Civilisation.	Geological Age.
Eolithic.	Stones in their natural condition are used as tools or utensils without being prepared for the purpose.	
Archeolithic.	Stones are artificially split, the fragments fashioned at the edges and adapted for use in various ways (as weapons or utensils), but do not as yet assume distinctive or conventional forms.	Middle tertiary.
Paleolithic.	As well as lithic instruments we find others of distinctive and conventional shape, made by breaking stones against each other. Towards the middle of this period we find the first signs of ornamental and figurative art.	Middle diluvial.
Neolithic.	Pottery, cattle-breeding, and agriculture begin. Lithic instruments are at first still made by means of percussion, later on they become more elaborate and are ground and polished.	Close of last glacial period.
Copper.	Copper is used for ornaments, weapons, and utensils, whilst the general character of the preceding civilisation remains unchanged.	About 3000 B.C.
Bronze.	Zinc and copper fused for the manufacture of tools.	About 2000 B.C.
First period of the iron age (Hallstadt's period).	Iron is used for the first time, whereas hitherto bronze has been employed for making tools, etc.	About 1000 B.C.
Second period of the iron age (La Tène's period).	The use of iron for the manufacture of implements becomes common.	From about 400 B.C. to A.D. 100.

Another problem of great importance is the origin of *artistic activity*. The different arts (figurative, ornamental art, sculpture, painting, music, in their various forms) are specific products of human activity, and they too have passed through primitive stages before reaching their present development, stages which we nowadays regard as crude and may still see amongst lower races.

Verworn thinks that the artistic sense first began to dawn at the beginning of the paleolithic age as conscious sense of form—that is, man then first began to show a preference for certain shapes, which he gave to the earliest works of his hands, articles made of stone.

Amongst the fossil remains of that period we constantly find implements of pyromacic stone of a conventional almond shape. Next we have the elaboration of bone objects, which we find more or less lavishly decorated with dots and geometrical lines symmetrically arranged. Another source of artistic activity is the desire to adorn the body either by hanging ornaments on it or by painting the skin.

We are astonished to find examples of figurative art dating from the middle of the paleolithic age, when man inhabited Europe in the diluvial period together with the reindeer, the mammoth, and the bison. In the caves of France articles and artistic representations have been found which reproduce the objects they depict with a skill and accuracy nothing short of marvellous. Amongst them are statuettes made of ivory, reindeer horns and bone representing animal or human forms; hunting scenes and outlines of animals then existing carved or painted on the walls of these caves, which reach such a high level of artistic excellence that they were at first supposed to be forgeries, a suspicion which is now considered to be quite devoid of foundation.

Verworn explains this surprising artistic ability of these primitive peoples by the theory that this art, which he terms *physio-plastic*, differs in its psychological origin from the art of more civilised races, which he calls *ideoplastic*. The former he regards as the product of immediate (and therefore natural) observation of the figure or mnemonic image without the intervention of speculation or reflection. Ideoplastic art, on the contrary, is not the immediate reproduction of visual sensation or of the mnemonic image thereof, since a higher psychic activity, the reasoning or imaginative faculty, enters into the reproduction. As examples of primitive ideoplastic art he gives the drawings of the Egyptians and of children, whose imaginative powers are clearly shown by the apparently incongruous and inartistic way in which they include in the drawing those parts of the body which are hidden by the clothing (Fig. 135).

With regard to the artistic ability of very primitive peoples to represent figures and hunting scenes, it should be borne in mind

that the Bushmen of the present day, who, like the ancient inhabitants of the French caves, are hunters, produce works of art astonishingly like those found in these caves.

The development of psychic human activities as a whole has kept pace with the morphological development of the different organs (more especially of the brain), of civilisation, and of artistic activity. We will consider more particularly the evolution of the understanding.

Verworn recently (1910, 1912) endeavoured to reconstruct the different phases through which the human mind has passed during the various geological ages.

He writes as follows: "The study of the development of the mind of man is an extremely complex problem, making demands

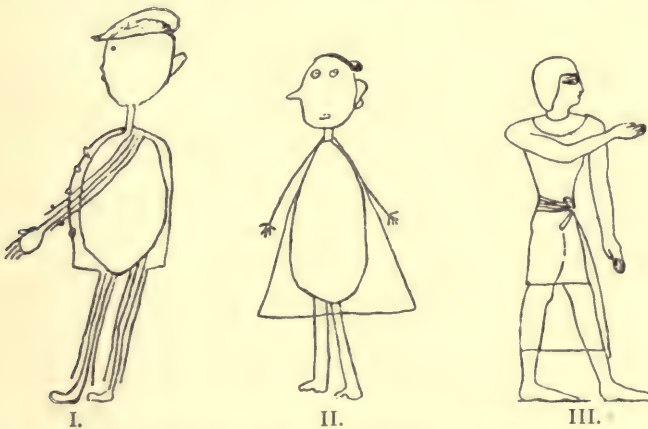


FIG. 135.—I. and II., drawings by children aged twelve years; III., Egyptian drawing dating from the time of the new dominion. The eyes and chest are drawn facing towards us, the lower limbs and face in profile, and the parts of the body which are hidden by the clothing are represented as showing through it. (Verworn and Erman.)

upon us of the most varied kinds. It requires the investigation of the most widely different sciences, which as a rule are never brought into contact with one another; such as theology and anatomy, ethnology and physiology, history of art and embryology, pre-history and pedagogy, zoology and technology. This renders the task extremely difficult, for where are we to find an investigator who is an expert in all these branches? The cut-and-dried methods of the scientific world, which refuses to recognise any science which is not supported by historical tradition and sanctioned by authority, force every investigator to turn *a priori* to one of these state-recognised branches of knowledge and expose any scientist whose problems lead him into realms of knowledge which appear far removed from one another to the ridicule of his more orthodox colleagues.

"When we consider the immense development of the different sciences in the present day, it would seem indeed almost impossible for one human intellect to master several such departments of learning. The problem of the development of the human intellect is therefore among the problems which have of late attracted but few students. Genealogical trees have been made showing the morphological development of the most diverse organisms, but we have not so far heard of *genealogical trees of human ideas*; yet every idea of which we make use to-day has not only a starting-point in the process of the ontogenetical evolution of the mind of the single individual in order to be elaborated later on, but has also a long philogenetical history, going back frequently to the origin of humanity, sometimes therefore to the animal series. A study of the philogenetical origin of all the essential elements constituting our present psychic life would undoubtedly be a task of great complexity, but would be as valuable as it is complex; its solution would go far into the ulterior development of the mind of man. We cannot doubt that this problem will attract more and more attention. Viewing its great complexity, it is comprehensible that until now only a few fragments of it have been studied."

After mentioning the researches into philosophy made by history (Lamprecht), and into comparative theology by history of religion, which are amongst the modern endeavours to solve some part of the problem of the development of human society, he dwells upon the importance for this purpose of the careful study of ontogenetical development, *i.e.* the psychogenesis of the child, a proof of Haeckel's fundamental biogenetical law, that the development of the individual is but a recapitulation of the development of the species.

The following table shows Verworn's attempt at a provisional reconstruction of the great stages traversed by the mind of man from the beginning of civilisation to our own day.

- | | |
|---|--|
| <p>I. <i>Period of Sensual Impressionism</i>.—The psychic life is dominated entirely by the sensations. The affections and the sensations are subject to sudden changes. The representative associations are still elementary and are directly related to passing sensations (psychic state of the higher animals).</p> | <p>Eolithic civilisation (tertiary period).</p> |
| <p>II. <i>Period of the Simple Practical Mind</i>.—The imaginative associations are no longer directly connected with the passing impressions of the senses, are already employed for practical deductions.</p> | <p>Archeolithic and paleolithic civilisation (late tertiary and diluvial).</p> |
| <p>A. First combination of ideas formed by casual observation for the purpose of practical inventions.</p> | <p>Archeolithic civilisation (late tertiary and archaic diluvial).</p> |

- B. Period of simple observation, practical inventions, and a simple sense of beauty. { Paleolithic civilisation (middle and late diluvial).
- III. *Period of the Theorising Mind.*—The association of ideas develops into more lengthy theoretical speculations more or less remote from the noted fact which is their starting-point. { From the close of paleolithic civilisation to the present time.
- A. Stage of dogmatic speculative thought. { From the close of paleolithic civilisation to the Renaissance in western countries during the fifteenth and sixteenth centuries after Christ.
- (1) Period of fantastic religious speculation. { Neolithic, bronze, and iron ages.
- (2) Period of scholastic and rationalistic speculation. { Greek, Roman, and mediæval civilisation.
- B. Stage of critical experimental thought. { From the Renaissance to the present day.

Closely connected with the question of the origin of man and the beginning of civilisation is that of the origin of the products of the *pastoral* and *agricultural arts*—*i.e.* of the plants and animals he has learnt to grow and domesticate for the supply of his needs and which have gradually become his most valuable heritage. The origin of domestic animals (oxen, sheep, pigs, horse, dog) does not present so many difficulties, since zoologists are fairly well acquainted with the species to which these animals belong, which are or were found wild, and could from the earliest times be used for breeding purposes in order to supply the ever-increasing needs of hunting peoples as game grew scarcer.

With our present knowledge we find more difficulty in solving the question of the origin of cultivated plants, and more particularly of those valuable plants which form the basis of agriculture amongst all civilised races, namely, corn and cereals in general.

This problem has been studied by noted botanists and palæthnologists, but so far without success. One thing only is beyond dispute: that corn is a plant which has been cultivated from time immemorial in Egypt, China, and central Europe.

Woenig has drawn attention to drawings by the ancient Egyptians of the cultivation and harvesting of corn which date from 3000 B.C., and Unger recognised remains of ears of wheat and barley in the brick-work of the pyramid of Dashur near Saquara, the clay of which these bricks were made being mixed with straw.

Bretschneider tells us that Szu-ma-tsien, the Herodotus of ancient China, related that the Emperor Shen-nung, who lived about 2700 B.C., used to celebrate the ceremony of sowing and reaping the five grains of corn, which symbolised the five kinds of cereals cultivated by the Chinese.

It has also been proved that the prehistoric peoples of central Europe were in the habit of growing corn. In the Swiss lake-dwellings O. Heer found remains of various kinds of wheat and barley cultivated in the present day.

How is the cultivation of corn in such far-away times and countries to be explained? Various theories have been suggested as a solution of this problem, but they one and all fail to carry conviction, more especially because botanists are not as yet certain from what wild vegetable species the different sorts of corn are derived. Koernicke, who has devoted many years to the study of this question, thinks that the primitive species is the *Triticum dicoccoides*, which is found wild in Palestine and Syria.

A clear synthetic account of the primitive inhabitants of Italy, and of the order in which the various prehistoric civilisations of the peninsula succeeded one another, has recently been given by L. Pigorini (1910). The remains of the earliest paleolithic civilisation are neither as numerous nor as interesting in Italy as in France and Belgium. The characteristic reindeer civilisation does not seem to have reached Italy; but in Italy, too, lithic weapons and implements have been found, which prove the existence of paleolithic races, living a nomadic life; they were probably hunters, inhabiting caves or other natural shelters, and did not honour the dead.

This earliest period was followed by that of neolithic civilisation, imported probably by immigrants from the east or south. These people left many remains behind which enable us to form a fairly correct idea of their culture. They had ceased to lead a nomadic life, and introduced the use of artificial habitations, consisting of round or oval huts half hollowed out of the earth, such as Vitruvius tells us were still customary in his day amongst the Frisians and are seen in our own day amongst the poor peasantry of Kasam in eastern Russia. These huts were grouped together so as to form villages, and from the fragments of bone found amongst the remains thereof it is supposed that these peoples were already acquainted with the pastoral art, since they include the bones of sheep, cattle, and pigs. They also knew something at all events of agriculture, as is proved by the impressions of grains of corn seen on their cooking-utensils (*Triticum diococcum*). Their weapons and implements were of polished green stone formed into axes, arrows, etc. They were also acquainted with the art of pottery, which they carried to a fair degree of perfection in their domestic utensils. With them

arose the custom of burying the dead and providing them with food, weapons, and tools, pointing to a belief in the resurrection of the dead or in the immortality of the soul. To this epoch belong the large, sometimes gigantic, sepulchres (*dolmens, megalithic monuments*) which amaze the scientists of our own day and bear witness to the honour paid to the dead by this people.

The neolithic age ends with the first metal implements in the form of copper axes and daggers, which do not, however, seem to have been introduced by fresh immigrants, but rather by commerce with oriental races who had already learnt the art of working in metal. At the same time the arts of making stone implements and pottery show great progress and we note the beginning of the textile industry: this period is known as that of *eneolithic civilisation*.

A new people with a new civilisation meanwhile appeared in eastern Italy, from Switzerland and the Danube, the people known as lake-dwellers from their characteristic dwellings built on piles in the lakes, who even on dry land continued to build wooden houses on piles thrust into the ground surrounded by moats into which they turned water from some neighbouring stream. They are known as the people and civilisation of the *terremare*—a word derived from *terra marna*, the term commonly applied to the soil in which the remains of these races are found—for our knowledge of whom we are indebted to the untiring and patient work of Pigorini and his pupils. This people carried weapons of *bronze*, and the many animal and vegetable remains found in their dwelling-places show that they had made great progress in agriculture and the pastoral art; we also find for the first time branches and seeds of the vine. They cremated their dead instead of burying them, collecting the ashes, which they preserved in vases or cinerary urns. Pigorini thinks that this civilisation flourished about 1500 B.C., and may be regarded as the cradle of Roman civilisation, in view of the absolute similarity between the method of establishing and building their homes adopted by this people and the Roman custom of founding cities or setting up encampments of which historic tradition tells us. The *bronze age* was succeeded by the *iron age*, in which the use of iron implements was introduced and the invention of writing gave a great impetus to the progress of civilisation. From this last of the prehistoric civilisations, which ends with the first historic civilisation in Italy (that of the Romans), there have come down to us many works of art and culture, which were dug up in the rich necropoli, such as the necropoli of the *Etruscans*, but we know little or nothing of their cities and dwelling-places, the remains of which have escaped the searches made by palethnologists.

VII. The question of the descent of man from lower animal forms is, as is well known, discussed by the most widely different

biological sciences. If we grant the doctrine of evolution, the question is implicitly answered in the sense that man as we know him to-day is descended from a lower form and has gradually developed, passing through various intermediate stages, until he reached his present form. What the causes and conditions were which determined, promoted, and facilitated this evolution, whether they were external or internal, is still under discussion. (See Chap. II., Vol. I.)

The animal form, which from the morphological point of view most closely resembles man as we know him to-day, is that of the monkey, as was recognised by Linnaeus, who placed man and the ape in the same class of the highest order of animals. Later researches have shown that all monkeys are not equally like man; the relationship is only strongly marked in the gibbon, the orang-outang, the gorilla, and the chimpanzee, which were therefore placed in a special class—that of the so-called anthropoid or anthropomorphous monkeys. The latest researches have proved this relationship still more plainly.

Whatever system of organs we select, we shall always find a great morphological resemblance between man and this group, so much so as to prove the truth of Huxley's assertion that the gap between anthropoids and man is relatively smaller than that between anthropoids and other monkeys.

The direction of the cavities of the eyes, which are separated by a bony septum, the characteristic shape of the pinna of the ear, the hairless palms and soles, the position and direction of the primitive piliferous system, and more especially the first stages of foetal development, are the same in man and anthropoid. Recent physiological, chemico-physiological, and pathological researches have shown this relationship to be even closer. Thus Friedental found that the blood of the anthropoid is the only kind which can be transfused into the blood-vessels of man without having the toxic effects which we have already seen (Chap. V., Vol. I.) to result from the transfusion of heterogeneous blood; this proves the blood of anthropoids and man to be homogeneous.

If we have recourse to the so-called *reaction to serum*, first proposed by Uhlenhuth, we arrive at the same conclusion. This reaction consists in giving on successive days some animal (rabbits are generally used) hypodermic injections of small quantities of the blood of other animals, which provoke in the animal experimented on, a reaction, the formation or increase of special proteid substances in the plasma of the blood, which precipitate certain proteid substances in the serum of the blood of the animal supplying the blood. This reaction takes place readily in a test-tube, even if only extremely small quantities of the two sera are used, and is specific for both animals. It has now been found that rabbits treated with an injection of human blood produce a serum

which precipitates that of anthropoid apes, as well as that of man. Another proof that the chemical and physiological constitution of anthropomorphous apes is fundamentally the same as that of man is afforded by the fact that certain diseases, such as syphilis, which were formerly supposed to be peculiar to man can be experimentally transmitted to these animals.

This does not, however, alter the fact of the existence of great and far-reaching differences between man as we know him and the anthropoid ape of the present day. Apart from the undeniable psychological differences which place man on a level so far above the rest of the living world, there are morphological differences characteristic of the human race. These are: the shape and capacity of the skull, the shape and weight of the brain, which are rightly considered of the greatest importance; the formation of a chin; the existence of an external nose; the redness of the lips; the characteristic distribution of the hair in the adult; the erect position and the differentiation of the function of the upper limbs, the hands, as the organs of touch and grasp, and of the feet as those of support in the erect attitude. Anthropomorphous apes use both upper and lower limbs for climbing trees. Recent palaeontological research has, however, shown man's erect attitude to be no recent acquisition, since it characterised various Saurians of the secondary age now extinct; apart from birds, the shape of whose skeleton differs too widely from that of man, the kangaroo and the bear are the only living animals who can adopt this position, and they only do so exceptionally.

Viewing these premisses, it is obvious that man must be descended from animal forms resembling the anthropomorphous apes of the present day; this does not, however, involve the hypothesis that these anthropoids represent ancestors of the human race who have happened to survive. On the contrary, it is far more probable that these animals and man are alike descended from some common ancestor, collateral branches of the same genealogical tree.

Klaatsch considers that at the beginning of the tertiary age a large number of lower mammals, with limbs and jaws possessing some of the characteristics of the apes of our own day, inhabited the then existing continents, a theory which is borne out by the researches of palaeontology and comparative anatomy. These mammals may be called *primatoids*, i.e. the original group from which were derived the various forms which gradually became differentiated in order to compose the three great groups of ape, anthropoid, and man. We may assume with Klaatsch that the common precursor of these three groups was a being who walked in a semi-upright position, but who usually climbed trees, whose trunk and limbs were of medium proportions, that is, whose arms and legs were of much the same length, whose feet and hands were suited to grasping things, whose skull was fairly

large and had well-developed jaws. The gradual development of man from this form was very simple: his skull and brain increased steadily in size until they assumed their present form, his back and spine became quite erect, and his foot changed from a grasping instrument into a means of support.

Between 1889 and 1893 E. Dubois found in the Island of Java, amongst other fossil remains of vertebrate animals, the skull cap



FIG. 136.—Diluvial skull of the Neander valley type (*Homo monstertiensis*) seen full face; anterior norm. (Klaatsch and Hauser.)

and left femur of a form of anthropoid ape unknown to zoologists among living forms, which he regards as the link between man and monkey.

As it must have been an anthropoid holding itself erect, he gave it the name of *Pithecanthropus erectus* (Batavia, 1894); it had a cranial capacity of about 850 to 1000 c.c. and a brain weighing at least 750 to 800 grms. The significance of these remains has been much discussed by both zoologists and anthropologists, and

they increasingly incline to admit that these remains must be those of a primitive form of anthropoid ape endowed with more characteristics of a primitive human form than are seen in the anthropoid ape of the present day.

Fossil remains of primitive human beings, which are of special interest to anthropologists by reason of the characteristics distinguishing them from the skeleton of modern man, were found in 1856 in the Neander Valley (Neandertal, Figs. 136 and 137), in 1886 at Spy (province of Namur in Belgium); in 1808 in Moustier (Dordogne); at Naulatte, Mauer-Heidelberg, Krapina, Chapelle-aux-Sains, Crô-Magnon, etc.



FIG. 137.—The same skull seen in profile; lateral norm.

All these fossil remains were taken from geological strata of the quaternary age and are characteristic by reason of their morphological features. Scientists naturally devote special attention to the characteristics of the skull; the cranial capacity of these remains, for instance, is markedly inferior to that of modern man, as will easily be seen on reference to Fig. 138.

The inferiority of these remains is also shown by other characteristics such as the shape of the femur (Fig. 139), the ocular orbit and the jaws; while the absence or very slight development of the chin as we see it in man of our own day is specially remarkable (Fig. 140).

There are other questions with regard to which scientists are either not agreed or have so far failed to solve; of these we will consider two: the part of the world in which the transformation of man took place and the precise determination of the progenitor of man. Two theories strive for the pre-eminence: one considers that man is derived from a single animal form and that his transformation therefore took place in a single spot (*monogenism* or the *monophiletic theory*); the other that the different human races are derived from various anthropomorphous forms, and that the transformation took place in different parts of the world (*polygenism* or the *polyphiletic theory*).

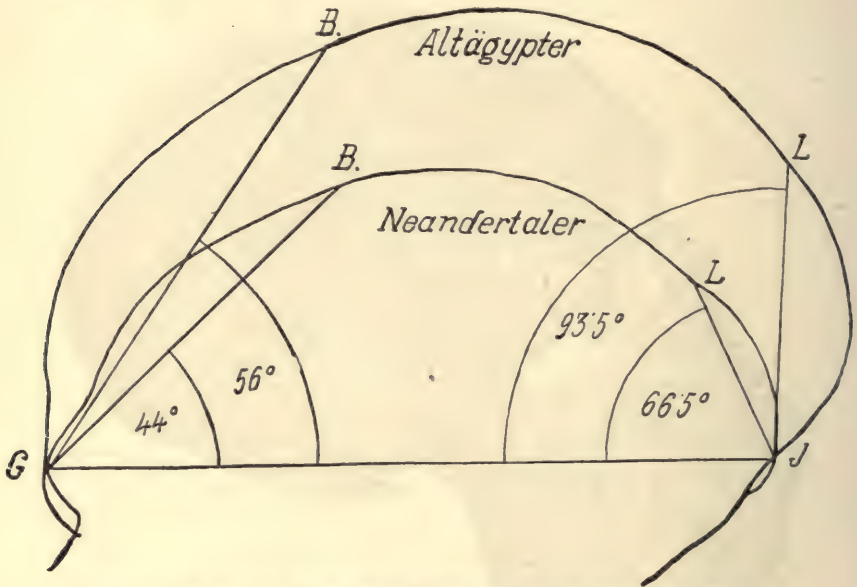


FIG. 138.—Median curves of the Neander Valley skull and of an ancient Egyptian skull by G. Schwalbe. (M. Hoernes.)

The arguments adduced in favour of one or other of these theories are all of a more or less indirect nature, and cannot be called absolutely convincing. They refer to the morphological characteristics common to the various existing human races or differing in them, and to those extinct characteristics of which we have fossil remains; to the general properties of heredity and reciprocal fruitfulness between individuals of the different races; to the characteristics of civilisation and culture distinguishing the various races from one another, etc. It will thus be seen that this problem is intimately connected with the fundamental question of evolution upon which we dwelt briefly in Chap. II. of Vol. I.

Darwin and Haeckel are amongst the advocates of monogenism, a doctrine which, as Hoernes observes, may be regarded as representing the ancient and traditional conception arising out of the religious ideas of humanity. Living anthropologists are divided in their opinions; the most ardent adherent of polygenism in Italy is Giuseppe Sergi, who has recently collected a mass of arguments against the monophiletic concept, while a more or less modified form of monogenism is advocated by Morselli and Giuffrida-Ruggieri.

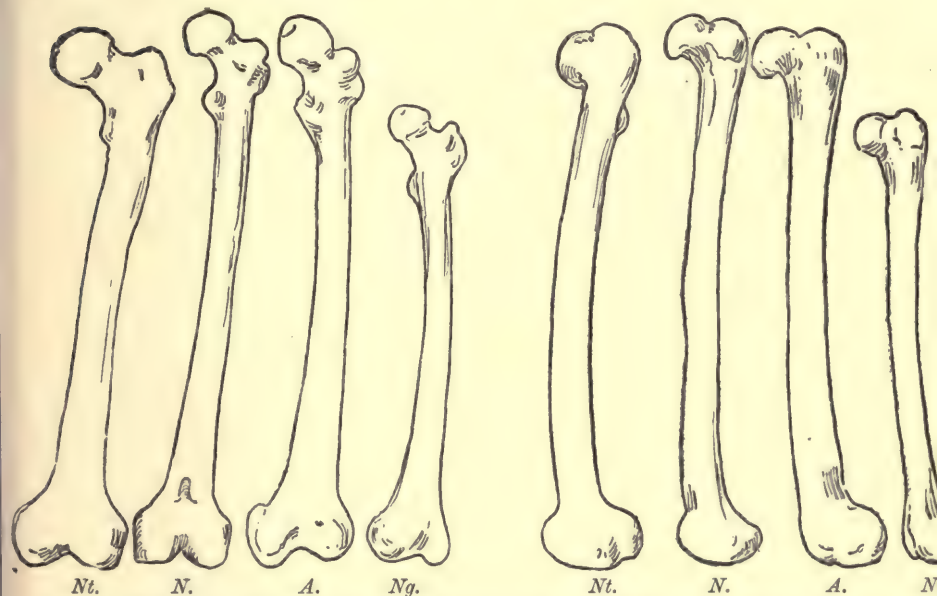


FIG. 139.—Femur of the Neander Valley skeleton (*Nt*) compared with that of an Australian (*A*), a Negro (*N*), and a Negrito (*Ng*) of the Philippine Islands, by Klaatsch. (M. Hoernes.) The drawing on the right shows the front, that on the left the side view of the same bones.

Sergi considers that comparative study of the different existing human races proves the existence of human groups which can be sharply distinguished from one another. In this comparative study the various anthropological and ethnical criteria which have hitherto been studied separately must be considered as a whole. Each of these human groups comprises in its turn a series of subordinate groups, having kindred characteristics; hence the necessity of giving another name to the groups of the former class and of not applying to them the terms "species" or "race," which should be reserved for those of the second class: he suggests the term "genus."

The main argument of monogenists is that individuals of

different sexes belonging to different races can interbreed and produce hybrids or half-castes who are fertile in their turn. Most biologists regarded this fact as proof positive of the affinity of species; Sergi, however, does not consider it of absolute value, since Morgan has proved that the degrees of sterility and fertility

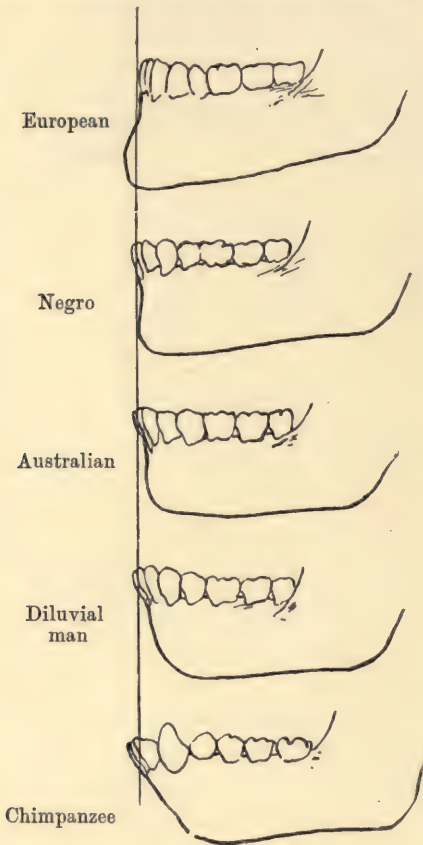


FIG. 140.—Development of the chin from the lower to the higher types according to Gaudray. (G. Buschan.)

vary enormously in the different species, both vegetable and animal, the product of some species which have been crossed being sterile hybrids, whilst others give rise to fruitful hybrids. He further points out (basing his remarks on Valeker's study of the crossing of primitive and white races) that the fertility of half-breeds is relatively extremely limited.

Morselli's monogenism is based on the arguments "that all human races show characteristics of the same type, more especially in those structural peculiarities of specific value to the zoologist, such as the type of the brain, the dentition and the teeth, the shape of the hands and feet, that of the lips, the hair in the armpits and on the pubis, etc. Facts of importance to the physiologist are, in addition to the fundamental fact of mutual fecundity, the equality of blood, the communicability of diseases, the like periodicity of men-

struation, the same period of pregnancy, the birth of not more than one child at a time as a general rule, the existence of bluish marks on the skin of new-born children of distant races, etc. Other witnesses to psychological unity are the marvellous universal phenomenon of articulate language, the great similarity in the method of giving expression to the emotions, in intellectual conceptions and creations, the forms of social organisation, and finally the proved capacity for education

possessed by all races, at least as far as the general tendencies of the mind and their adaptation to conditions compatible with civilisation are concerned."

The monogenism advocated by Morselli is not, however, absolute, but modified in so far as he admits that one primitive form gave birth to various species; it is a *polyphyletic monogenism*. He writes: "The existence of human forms differing specifically from the one in existence at present, which became extinct during



FIG. 141.—Dravidian Mandracian (*Notanthropus euraffricanus dravidicus*). (G. Sergi.)

the palaeo-quaternary ages, is no proof that living man who has survived the latest geological vicissitudes is a whole made up of various species; can we deny the specific limitations of the living horse and the orang-outang, because the American horse and the *Palaeopithecus sivalensis* have ceased to exist? Monogenists of to-day may perfectly well affirm that *Homo* is a genus of which several species have become extinct, and only one has survived; without, however, denying that this species may have originated after or at the same time as sub-specific varieties of a single type in places which, though at no great distance from one another

were somewhat different, in a single continental centre of formation. The single character of the hypothesis will be preserved, provided we do not enlarge the borders of this centre and that we recognise that the strong likeness between all mankind proves that it cannot be derived from very widely different forms, but inclines us to believe at most that it originated in a single slightly differentiated and therefore very plastic form, under conditions of life very different from those now existing."



FIG. 142.—Warrior of Berbera, Somaliland (*Notanthropus eurafricanus africanus*). (G. Sergi.)

Giuffrida-Ruggieri, regarding, as he does, the human genus as a collective species, composed of various elementary species, eight in number, which he classifies in substantially the same way as Sergi, merely applies certain general concepts of modern biologists (De Vries, Cuenot, with which we dealt in the second chapter of Vol. I.).

We are forced to grant that at present the two doctrines are striving for the mastery, but that so far no decisive argument has

turned the scale in favour of either the one or the other; it may be that the time is not yet ripe. We must hope that the discovery and study of other fossil human remains and further examination of the characteristics of the different living races may lead to more profitable discussion of the problem and in time to its solution.

Different classifications of the human races from the point of view of monogenism and polygenism will be given later.

VIII. Another argument much discussed in anthropology is that of the classification of the human races. The difficulties encountered in this problem are closely connected with the value



FIG. 143. —Polynesian women (*Notanthropus euraficanus polynesianus*). (G. Sergi.)

and importance attributed to the different morphological and distinctive characteristics which we have already mentioned and which have been regarded by various writers as differential characteristics on which to base their classification. We have seen in fact that no one of the said characteristics suffices for the demarcation of limits separating the different races sharply from one another; one and all prove to have intermediate stages which gradually join the extremes.

In general it may be said that the more numerous and more thorough the researches into the different morphological characteristics, the more do scientists tend to increase the number of groups into which the human race can be divided.

Linnaeus (1707-1778), the father of modern classification, after having placed the genus man in the first order of mammals, which he termed *primati*, and in which he also included monkeys, pre-monkeys, and bats, subdivided the genus into four varieties or races: *American*, *European*, *Asiatic*, and *African*, basing his classification on geographical distribution rather than on morphological characteristics. The attributes assigned by him to each group were partly morphological, partly ethnical, and partly



FIG. 144.—Toda (*Notanthropus eurayricanus toda*). (G. Sergi.)

psychological in their nature, as will be seen from the following literal translation which we quote from Ranke's work.

1. Man (*Homo sapiens*). Know thyself.

(1) *Homo diurnus*, varying according to his culture and dwelling-place; of him there are four varieties:

(a) The American (*Americanus*): Reddish, passionate, holding himself erect. Straight, black, coarse hair, wide nostrils, face much freckled, almost no beard. Obstinate, contented, free, coloured in labyrinthine lines (dedalic), subject to laws.

(b) The European (*Europæus*): Fair, sanguine, fleshy; yellowish curly hair; blue eyes; intelligent, active, ingenious; wears tight-fitting garments; is subject to laws.

(c) The Asiatic (*Asiaticus*): Yellowish, melancholy, tenacious; blackish hair and brown eyes; cruel, fond of luxury, avaricious; wears loose flowing garments; ruled by his opinions.

(d) The African (*Afer*): Black, phlegmatic, slow; jet black, tightly curled hair; flat nose, thick lips, smooth, silky skin like velvet, the women have the 'apron' of the Hottentot women, and the breasts become elongated when they are nursing (*Feminae sinus pudoris, mammae lactantes prolaxae*). Shrewd, lazy, indifferent; skin covered with grease; governed by caprice.

Blumenbach (1795) was the first to attempt to make use of the characteristics deduced from a more thorough study of the skull, the face, the colour of the skin, etc. His classification, which was approved and copied by Joh. Müller, had and still has many adherents; he divides the genus man into *five* races.

(a) *The Caucasian Race*:

White, rosy-cheeked, brown or chestnut hair and rounded skull. Oval face, with no disproportionately prominent parts; somewhat flat forehead; rather

narrow and slightly small mouth; incisors perpendicular in both the jaws; lips moderately developed; full, rounded chin; the features are generally delicate and beautiful.

To this race belong Europeans (with the exception of Laplanders and Finns), the natives of western Asia as far as the river Ob, the Caspian Sea and the Ganges, and the natives of North Africa.

(b) *The Mongolian Race*: Yellow skin; black, straight, thin



FIG. 145.—Young girl of the Akka pigmy race (*Notanthropus pygmaeus dolichomorphus*). (G. Sergi.)

hair; large, flat face; small, flat, wide nose; eye-lid fissure narrow and oblique; eyes very far from one another.

To this race belong the remaining Asiatics (with the exception of the Malays), Finns, Laplanders, North Americans, Eskimos, and Greenlanders.

(c) *The American Race*: Copper-coloured; straight black hair; more or less scanty beard; prominent nose.

This race comprises the remaining Americans.

(d) *The Ethiopian Race*: Black or dark brown; thick, short,



FIG. 146.—Hottentot woman (*Notanthropus australis*). (G. Sergi.)

woolly, black hair; skull long and laterally compressed; retreating forehead; prominent upper jaw and retreating chin with teeth set slanting forwards; small nose depressed at the root; thick lips.

To this race belong the remaining Africans or Negroes, the negroes of New Holland and of the Indian Archipelago (Papua).

(e) *The Malay Race*: Brown skin; abundant soft black hair, growing in ringlets; moderately narrow skull; convex forehead; rather prominent lower jaw; thick, wide nose; thick lips; large mouth.

To this race belong the inhabitants of the islands of the Pacific;

those of the Marianne, Philippine and Molucca Isles, of Sonda and of the Malay Peninsula.



FIG. 147.—Negrito woman from Luzon in the Philippine Islands
(*Notanthropus pygmaeus oceanicus*). (G. Sergi.)

We will mention the most noteworthy of later classifications. Huxley (1870), taking as his basis the morphological characteristics



FIG. 148.—Bushman (*Notanthropus australis humilis*). (G. Sergi.)



FIG. 149.—Vedda of Ceylon (*Notanthropus pygmaeus ceylonensis*). (G. Sergi.)



FIG. 150.—Ardi (Javanese) (*Ileoanthropus orientalis submalayensis*). (G. Sergi.)



FIG. 151.—Alsatian (*Hecanthropus eurasicus europaeus*). (G. Sergi.)

of the whole body, divided humanity into five groups: the Australoid, Negroid, Mongoloid, Fair (*xanthocroid*), and Mediterranean brown (*melanocroid*) types. Friedrich Müller (1879) based his classification more especially upon the characteristics of the skin, hair, and language, and divided mankind into two main groups: woolly-haired (*ulotrichi*) and smooth-haired (*lissotrichi*).

He subdivided the *ulotrichi* into (*a*) Lofocomi (Hottentots, Papuans); (*b*) Eriocomi (African negroes and Kaffirs). The



FIG. 152.—Chinaman (*Heoanthropus sinicus*). (G. Sergi.)

Lissotrichi fall into (*a*) Euticomi (Australians, Hyperboreans or natives of the Arctic regions, Americans, Malays, Mongolians); (*b*) Euplocomi (Dravidians, Nubians, and the peoples of the Mediterranean).

Topinard (1885) divided humanity into three groups, consisting of nineteen different races: (*a*) White, leptorhinous races (Anglo-Scandinavian, Western Finns, the Mediterranean peoples, Semitic-Egyptians, Lapp-Ligurians, Celtic-Slav); (*b*) Yellow, mesorhinous races (Eskimos, Tehuelcis, Polynesians, Red Indians, Yellow Asiatics, South Americans, Peruvians); (*c*) flat-

nosed, Black races (Australians, Negroes, Tasmanians, Negritos). Closely connected with the question of the classification of the genus man is that of his origin—a question which is being much discussed at the present time, but is still far from being finally and definitely solved. The researches made with a view to the solution of this supreme problem have, however, yielded important results: they proved the existence of extremely ancient human skeletons, which, as we have already seen, show morphological characteristics very different from those of the



FIG. 153.—Tibetan women (*Homoanthropus orientalis tibetanus*). (G. Sergi.)

skeleton of modern man; hence in recent classifications it has been thought necessary to assign a place to the extinct human races. Of recent classifications of the genus man, we will mention Haeckel's *monogenetic* (1908) and Sergi's *polygenetic* schemes.

Haeckel, who had previously accepted the classification proposed by Friedrich Müller, suggests a provisional division of the genus man into five species and twelve sub-species, as follows:

(1) *Homo primigenius* (extinct species of the tertiary geological age, originating in southern Asia): He has left fossil remains in the diluvial stratum in Europe (the Neander Valley, Spy, etc.) and in certain Australian strata (Palinander).

(2) *Homo phaeodermus* (Australoid species, the dark brown human species of Australia). He has preserved many characteristics of the *Homo primigenius*: markedly dolichocephalic skull, prognathous, retreating forehead, with the upper orbital edges raised; black hair growing in ringlets (cimetrichi). The main branches are represented by the natives of New Holland (Neoranis), the Veddas, and Dravidians.



FIG. 154.—Siamese (*Heoanthropus arcticus siamensis*). (G. Sergi.)

(3) *Homo meladermus* (Negroid species, black human species): The skull is usually extremely dolichocephalic, prognathous; black woolly hair (ulotrichi). The hair is sometimes fleecy and uniformly distributed (eriacomi) as in Negroes and Kaffirs; sometimes grows in tufts (lofocomi) such as Hottentots and Papuans. The most primitive varieties of this species are the Negritos of the Malay peninsula and the pigmies (Akka) of Africa, from whom sprang the Hottentots and Bush peoples. Secondary varieties of

a higher type are the Papuans and Melanesians on the east and the African negroes on the west.

(4) *Homo xanthodermus* (Mongoloid species, yellow human species): The skull is usually extremely brachycephalic, frequently also mesocephalic; face broad and flat with prominent zygomatic arch; skin usually has but a weak growth of hair and is yellowish in colour; stiff, smooth hair (lissotrichi or euticomi). The Malays, from whom have sprung the Polynesians, Maoris, and inhabitants of Madagascar, are a primitive variety of this species. The special characteristic of the yellow race is developed most strongly in Eastern Asia (Indo-Chinese and Korea-Japanese). The Finns and



FIG. 155.—Japanese women (*Heoanthropus orientalis japonicus*). (G. Sergi.)

Magyars, Hyperboreans and natives of the Arctic regions are secondary varieties of this species. The natives of America are descended from one or more branches of it.

(5) *Homo leucodermus* (Mediterranean species, white human species): The skull varies considerably, is usually mesocephalic, but may be both dolichocephalic and brachycephalic. The piliferous system is more highly developed than in Mongoloids and Negroids, and resembles that of Australoids; the luxurious beard and wavy hair are specially noticeable (cimotrichi or euplocomi). The primitive varieties were dark and derived from the Australoids (Dravidi). The secondary varieties which emigrated from India to the West developed in North Africa and formed the Nubian races

(ancient Egyptians, Nubians, Dongolians, Fellah) and were the principal stems in south-east Asia from which the Semitic and Indo-Germanic races were derived.

Sergi affirms that all living men can be divided into three species, to which we must add two extinct races. There are three clearly distinguishable *facies*, corresponding to the three living species: the *facies africana*, which is geographically very wide-



FIG. 156.—Eskimo (*Hesperanthropus Columbi esquimensis*). (G. Sergi.)

spread; the *facies asiatica*, which is rather less so; and the *facies americana*. Sergi considers that since at the present day these three human types inhabit distinct geographical areas, there being only a small geographical district on the boundary between European Asia and Africa where mixed types are found, there is good foundation for the hypothesis that these three types have an autonomous and local origin (polyphiletic origin).

We refer the reader who is desirous of detailed information to

Sergi's book, and merely reproduce his classification with a few illustrations showing the single human groups.

(1) *Palaeanthropus*: Extinct European genus; with the species of European *Palaeanthropus* (Neander Valley, Krapiniense, Heidelberg).

(2) *Archaeanthropus*: Another extinct genus found in South America (Patagonia); with the species *A. del Pampa*.

(3) *Notanthropus* (man of the south): Original genus of the African continent (Figs. 141 to 149). Its char-

acteristics are: bimorphous or elongated skull (dolichomorphous) in the species over and about average height; short and rounded (brachycephalic or mesocephalic) in the pigmies; the face varies in length and width, is sometimes ortognathous, sometimes prognathous, small or flat-nosed; the eyes are horizontal with full oval eyelids; the iris varies in colour; the hair is cimetrichic or ulotrichic; white or coloured skin; hair sometimes abundant, sometimes scanty; height variable. This genus includes the following species: (a) *Eurafricanus* (comprising groups inhabiting Africa and Europe, amongst them); Northern, Mediterranean, African, Dravidian, Polynesian, Australian, and the Todi-Ainus); (b) *Afris* (comprising the varieties: Ethiopian, Negro, Silvestrian African, Libyan); and finally (c) the species *Austral* (comprising the variety known as pigmies).

(4) *Heoanthropus* (man of the east): A genus originating in the continent of Asia (Figs. 150 to 155). Their characteristics are: bimorphous skull (dolicho- and brachymorphous); broad, short face, almost always ortognathous, short, depressed nose; Asiatic (Mongolian) eye, narrow eyelid, tending to be triangular in shape; the plica semilunaris very frequent; yellow skin; hair



FIG. 157.—Indian boy from Gran Cacao, Paraguay.
(*Hesperanthropus Columbi paraguayensis*). (G. Sergi.)

growth poor or scanty, straight and black; height variable. It comprises the species: (a) the *Arctic* peoples (including Finns, Siamese, Malays); (b) *Eur-asiatics* (or the inhabitant of Europe and Asia, including Italians, French, Germanic, Balcan, Russian); (c) *Oriental*s (including Japanese, sub-Malay, Tibetan).

(5) *Hesperanthropus* (man of the west): Genus originating in



FIG. 158.—Tuelco of Patagonia (*Hesperanthropus patagonicus*). (G. Sergl.)

the American continent (Figs. 156 to 158). Its characteristics are: polymorphous skull; face usually broad, nose generally leptomesorhinous. Red, russet, or chocolate-coloured skin; eyes horizontal (occasionally oblique) and dark; smooth, stiff, black hair, occasionally wavy, little or no hair on the rest of the body. It comprises two species, the first embracing the largest number of varieties (Eskimo, natives of Planitia, Sonora, the Amazon, Paraguay, the Andes); the second represented by the Patagonians.

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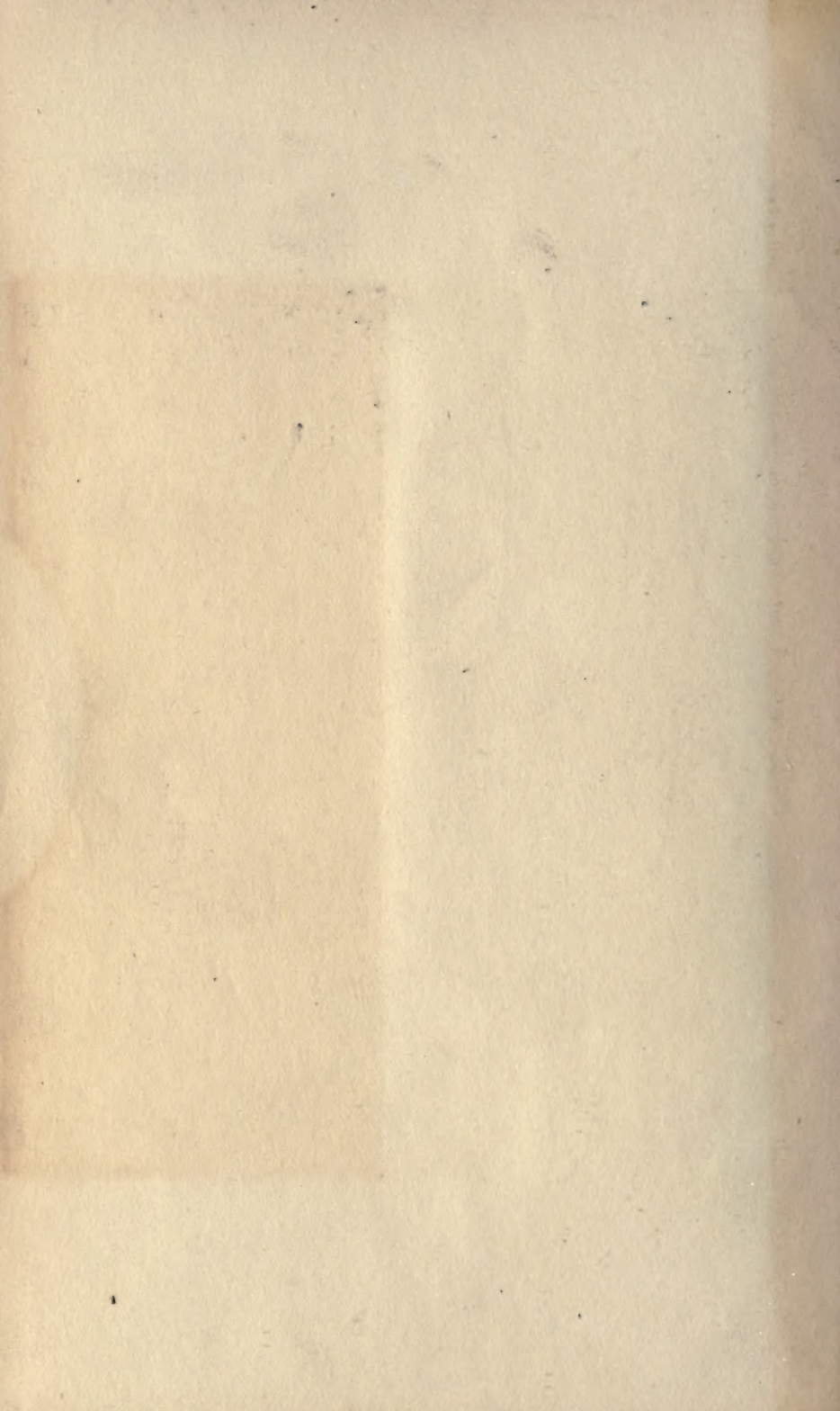
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